METHODS OF EXCAVATION AND ROOF SUPPORT USED IN SOME RECENTLY CONSTRUCTED TUNNELS

BY S. P. POLACK

* * * * * * * * * **Information Circular 7568**

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INTRODUCTION

The purpose of this circular is to correlate the information obtained during personal investigations at the sites of four rock tunnels in the process of construction and information obtained from the records and personal views of the constructors of two other tunnels that were not visited during the excavation phase of construction and to present this information for the benefit of those who contemplate future construction of rock tunnels.

Modern mechanized coal mining requires better, safer, properly alined haulageways and beltways; consequently, better understanding of tunneling methods by coal-mining men will be necessary. The possibility of future high-speed haulage systems utilizing rock tunnels in the more solid rock strata above or below the coal beds must not be discounted. In the past, tunnels have been driven for use in draining and unwatering inundated coal mines. At present, the need for such tunnels is very evident in some parts of the coal-mining regions, notably in the Pennsylvania anthracite fields, and studies along these lines are in progress. The average coal-mining man has little time or opportunity to visit tunnels while they are being excavated; therefore, it is hoped that this information will assist him in constructing tunnels safely if he is required to do so in the future.

The tunnels described herein differ in size, shape, usage, and, in many instances, in their geological aspects. Full-face, heading and bench, and pilot-tunnel and enlargement methods of excavation were utilized.

The roof-support methods show diverse designs and materials of construction to suit each purpose and condition. The superiority of steel roof support over wood is demonstrated beyond doubt and is shown clearly in the photographs included in this circular.

The illustrations (photographs taken by the U. S. Bureau of Mines, the U. S. Corps of Engineers, and others) show many of the necessary steps taken during the excavation and the erection of roof support in tunnels under construction.

The use of gasoline-powered equipment underground during the construction of some of the tunnels listed should be noted. It should be emphasized that the Bureau of Mines is opposed to the use of gasoline-powered equipment for underground operation, not only because of the carbon-monoxide emissions but also because of the fire and explosion hazards that result from its use.

ACKNOWLEDGMENT

The author gratefully acknowledges the cooperation and assistance given by the supervisors and other employees of the Herman Holmes Co.; Bates & Rogers

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Construction Co.; Hunkin-Conkey Construction Co.; Shofner, Gordon, & Hinman; and B. Perini & Sons, Inc., Assoc., contractors; the personnel of the Corps of Engineers, U. S. Army, Pittsburgh district; and the Pennsylvania Department of Highways. The assistance of F. B. Kissell, district safety engineer, Corps of Engineers, the Photogenic Section of the Corps of Engineers, and the Graphic Services Section, Bureau of Mines, was of inestimable value and is hereby particularly acknowledged.

SALTSBURG TUNNEL (PENNSYLVANIA RAILROAD)

The Saltsburg tunnel, a double-track railroad tunnel, was constructed by the Herman Holmes Co. near Saltsburg, Indiana County, Pa., under the direction of the Corps of Engineers, U. S. Army, in the relocation of part of the Conemaugh Division of the Pennsylvania Railroad, so that about 16 miles of the present railroad right-of-way may be abandoned in completing a dam and flood-control project.

The Saltsburg tunnel is approximately 2,660 feet long. Before starting the main bore, a pilot tunnel (fig. 1), approximately 15 by 15 feet, with arched roof, was driven by the full-face excavation method through the entire length (fig. 2). The roof of the pilot tunnel was not supported, except near the portal. A small power shovel and mine cars operated on a 36-inch gage track were used for mucking (loading blasted material) in the pilot tunnel. Holes were drilled with water-lined pneumatic drills mounted on vertical and horizontal columns. The ventilation pipe, compressed-air and water pipe lines, and power wires are shown in figure 2. A common vertical center line was used for the pilot tunnel and the main-bore enlargement. The bottom of the pilot tunnel was about 2 feet above the bottom of the main-bore enlargement. The finished tunnel was approximately 36 feet in width and 34 feet in height, with an arched roof, and the cross-sectional area was approximately 1,000 square feet. The direction of the tunnel is approximately N. 38° W. or S. 38° E., and the grade is 0.3 percent ascending from northwest to southeast. The difference in elevation of the portals is 8 feet.

The excavated rocks consisted of bedded and cross-bedded shales, clays, limestones, and sandstones. These formations ranged in color from light to dark gray and from soft, through medium, to hard and often were "silty." The tunnel is in a bituminous-coal region, and coal streaks were encountered. Partings were frequent and pronounced at many locations; therefore, considerable difficulty was encountered in breaking roof rock to a definite arch. The rock cover ranged from a few feet to a maximum of about 360 feet.

The pilot tunnel was enlarged in excavating for the final tunnel. A drill carriage (jumbo) moving on gantry rails was used as a drilling platform. Nine pneumatic drills were mounted on the wings and the top deck of the jumbo (fig. 3). Generally about 105 holes, each 10 feet deep, were drilled for each round and charged with 40-percent-strength gelatin explosive. The explosive was initiated by electric delay detonators (0 to 8). Approximately 275 pounds of explosives were consumed for each round.

Operations during the mucking cycle were as follows: After blasting and the removal of explosive fumes, a Diesel-powered bulldozer entered the

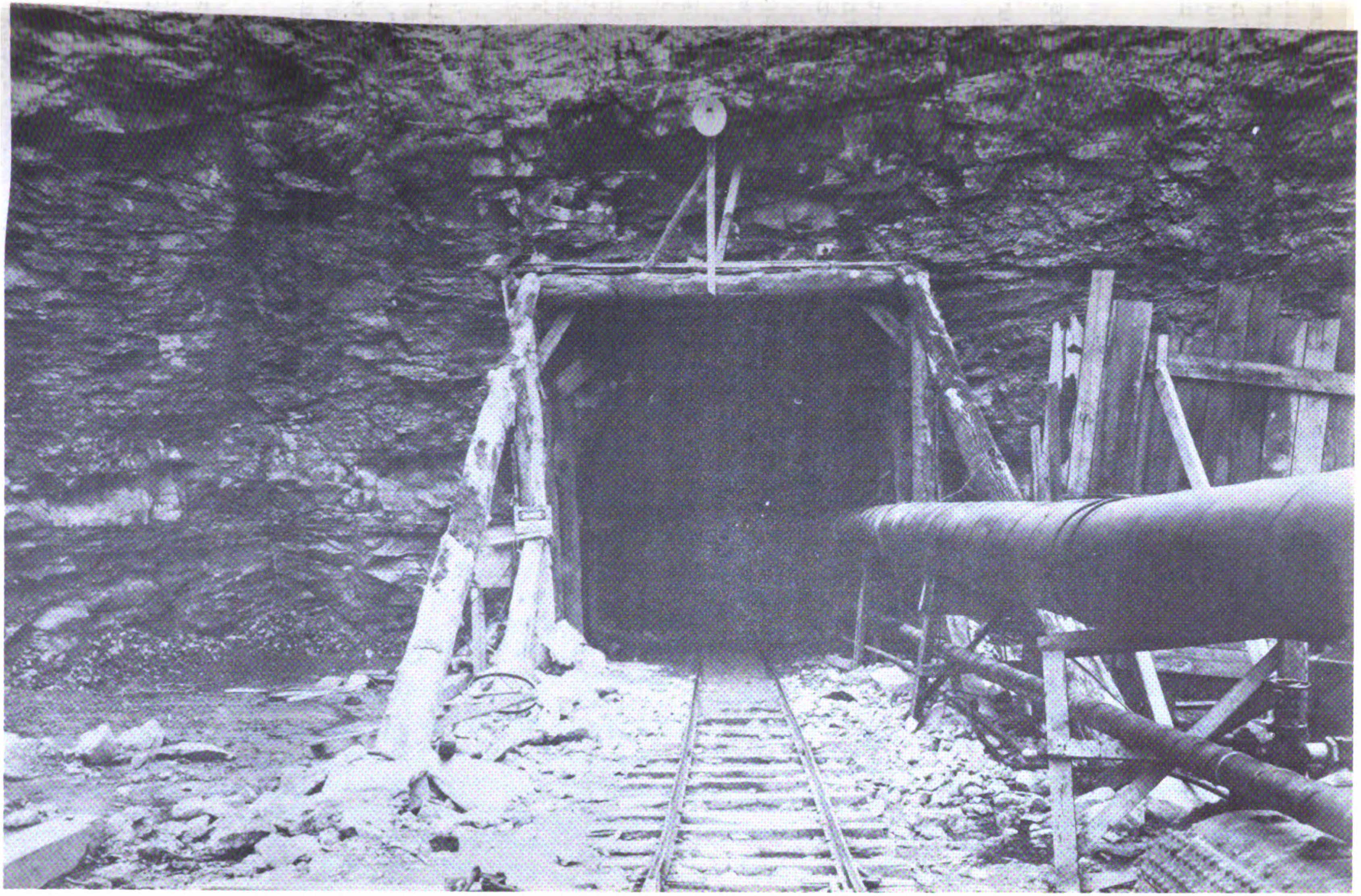

Figure I. - West portal of pilot tunnel, Saltsburg tunnel.

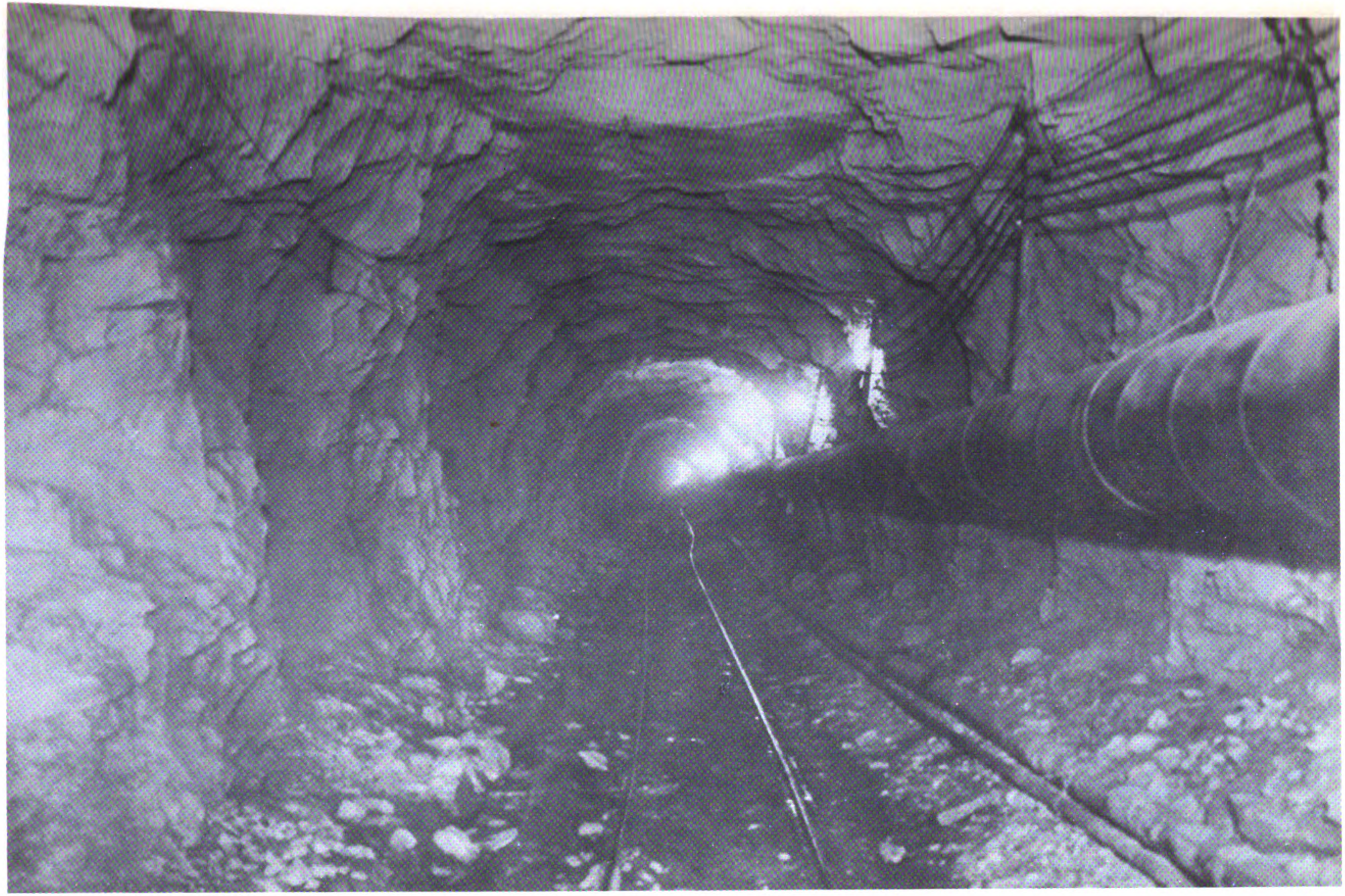

Figure 2. - Interior of Saltsburg pilot tunnel, showing narrow-gage track, power lines, ventilation duct, and air and water lines.

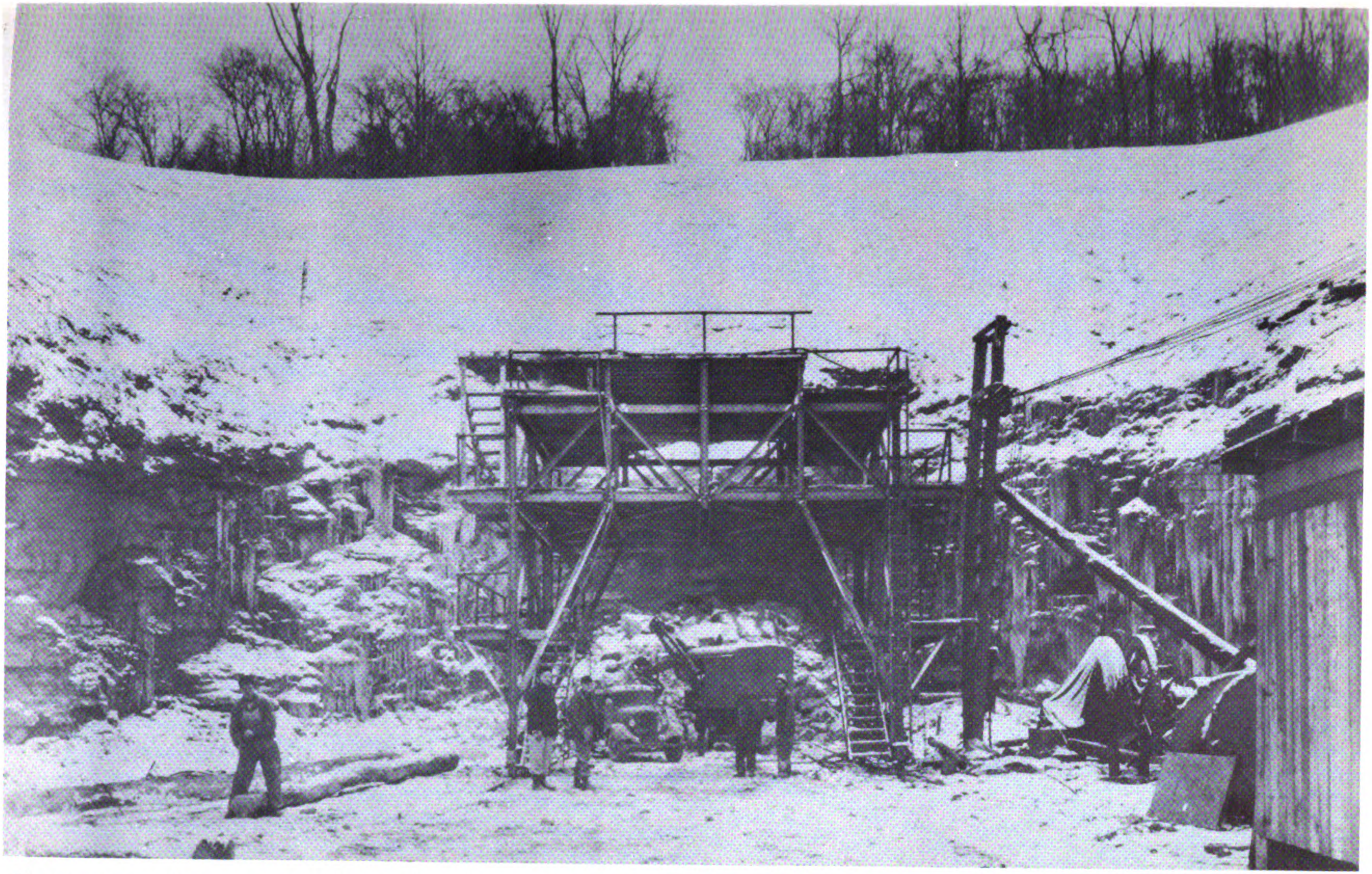

Figure 3. - Enlargement (large bore) at west portal of Saltsburg tunnel, showing drill carriage (jumbo).

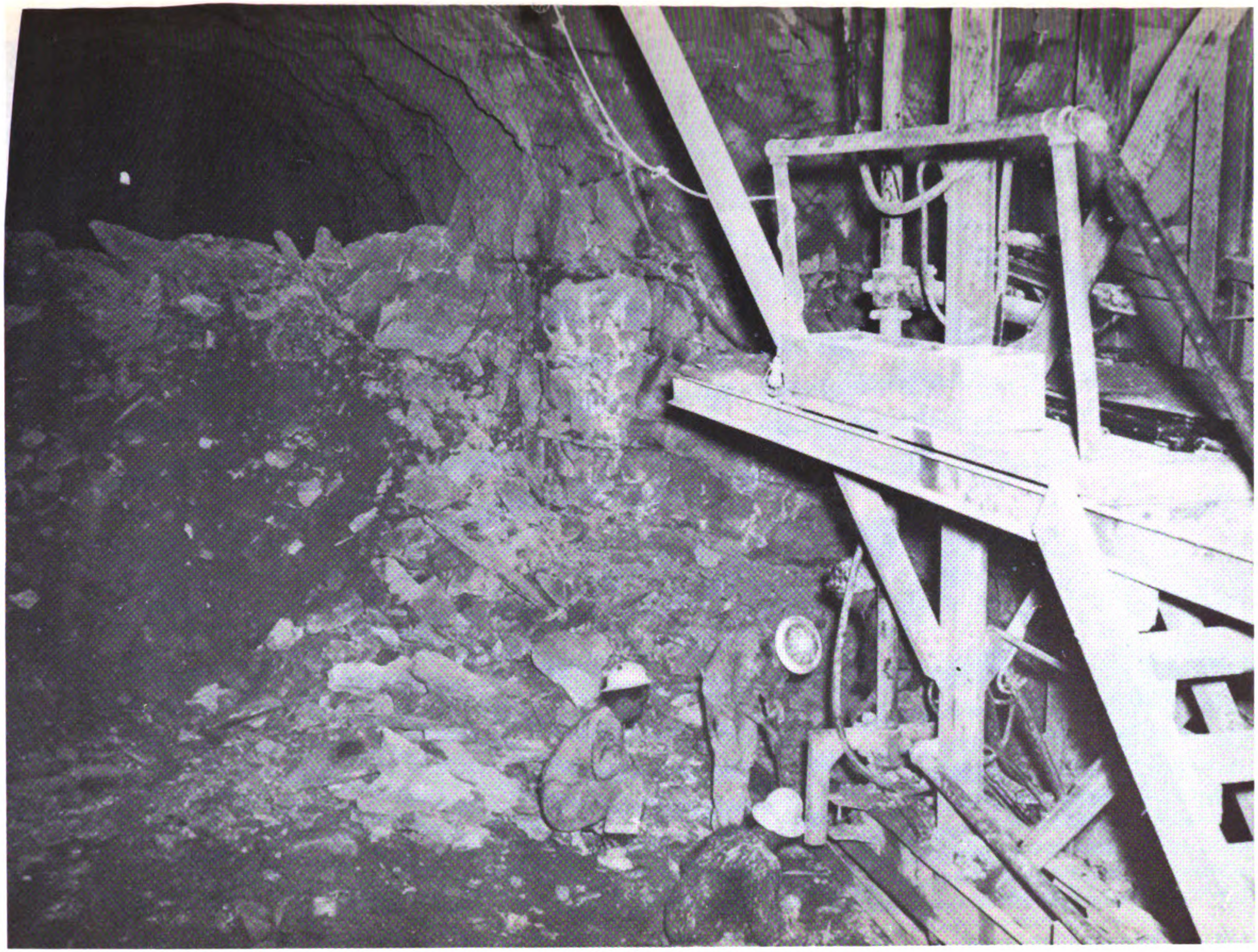

Figure 4. - Extending gantry rail before moving jumbo. Holed-through pilot tunnel also shown.

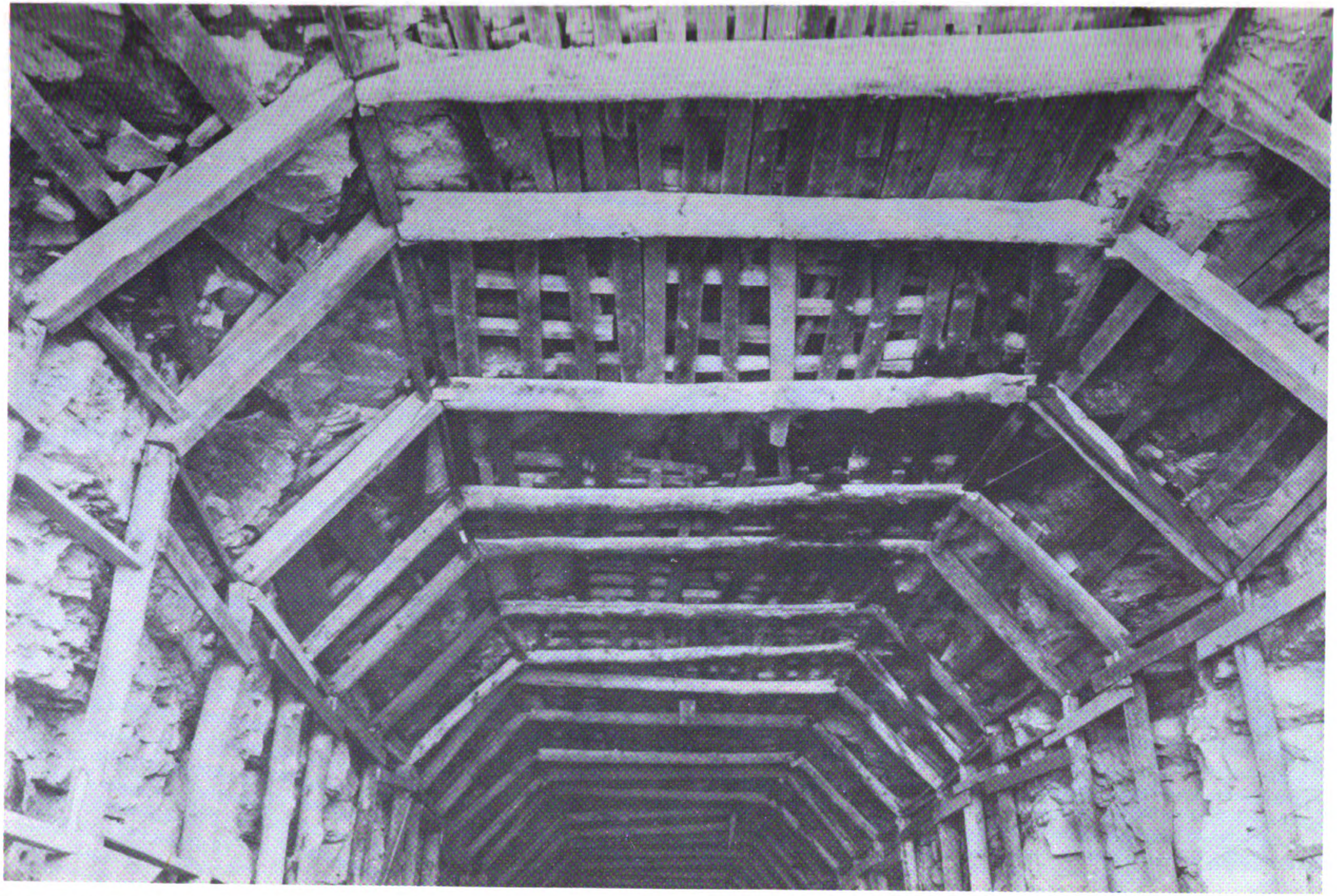

Figure 5. - Interior of Saltsburg tunnel, showing wood-timbering details. Lagging improperly blocked.

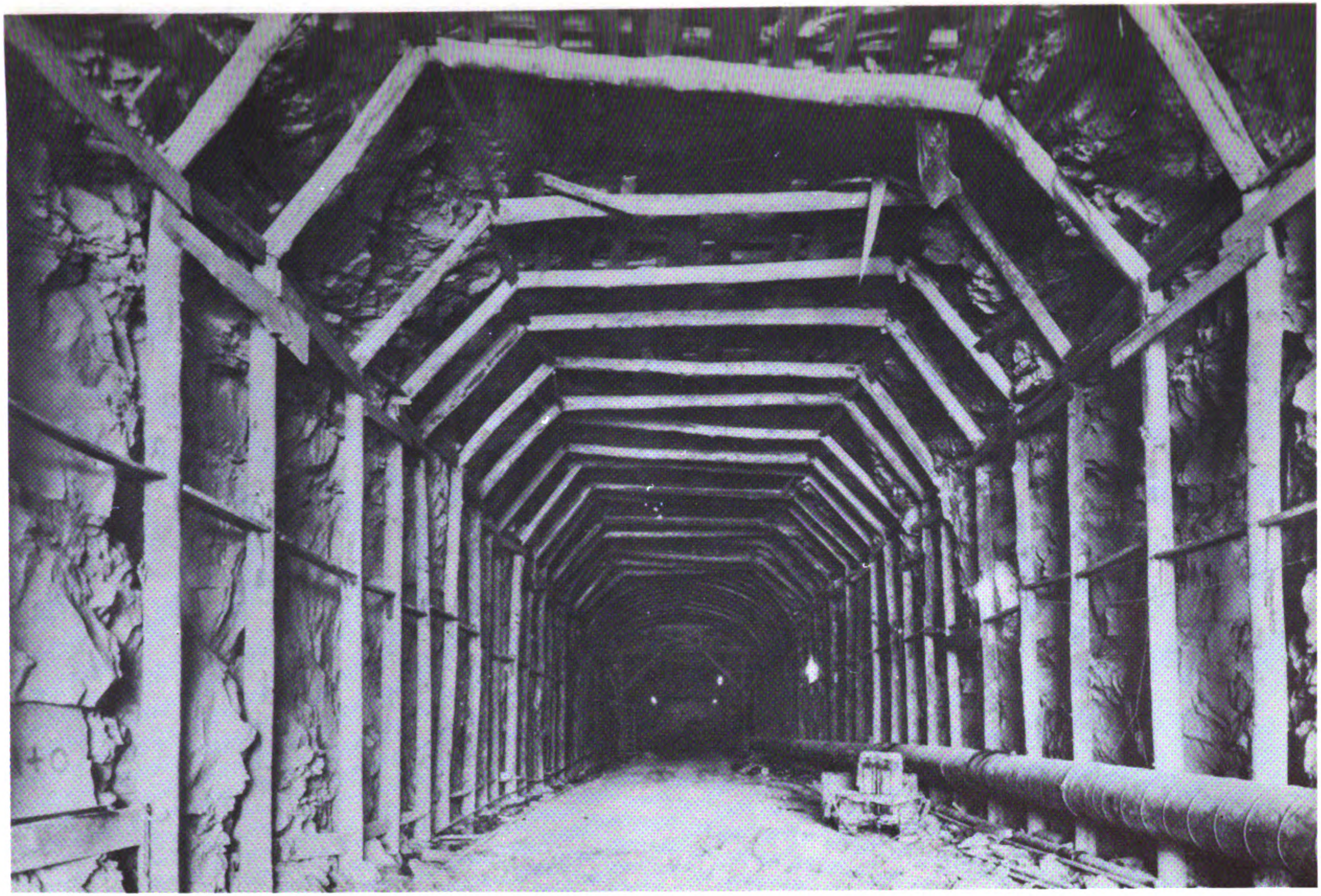

Figure 6. - Interior of Saltsburg tunnel, showing where rock fell from roof through improperly blocked lagging.

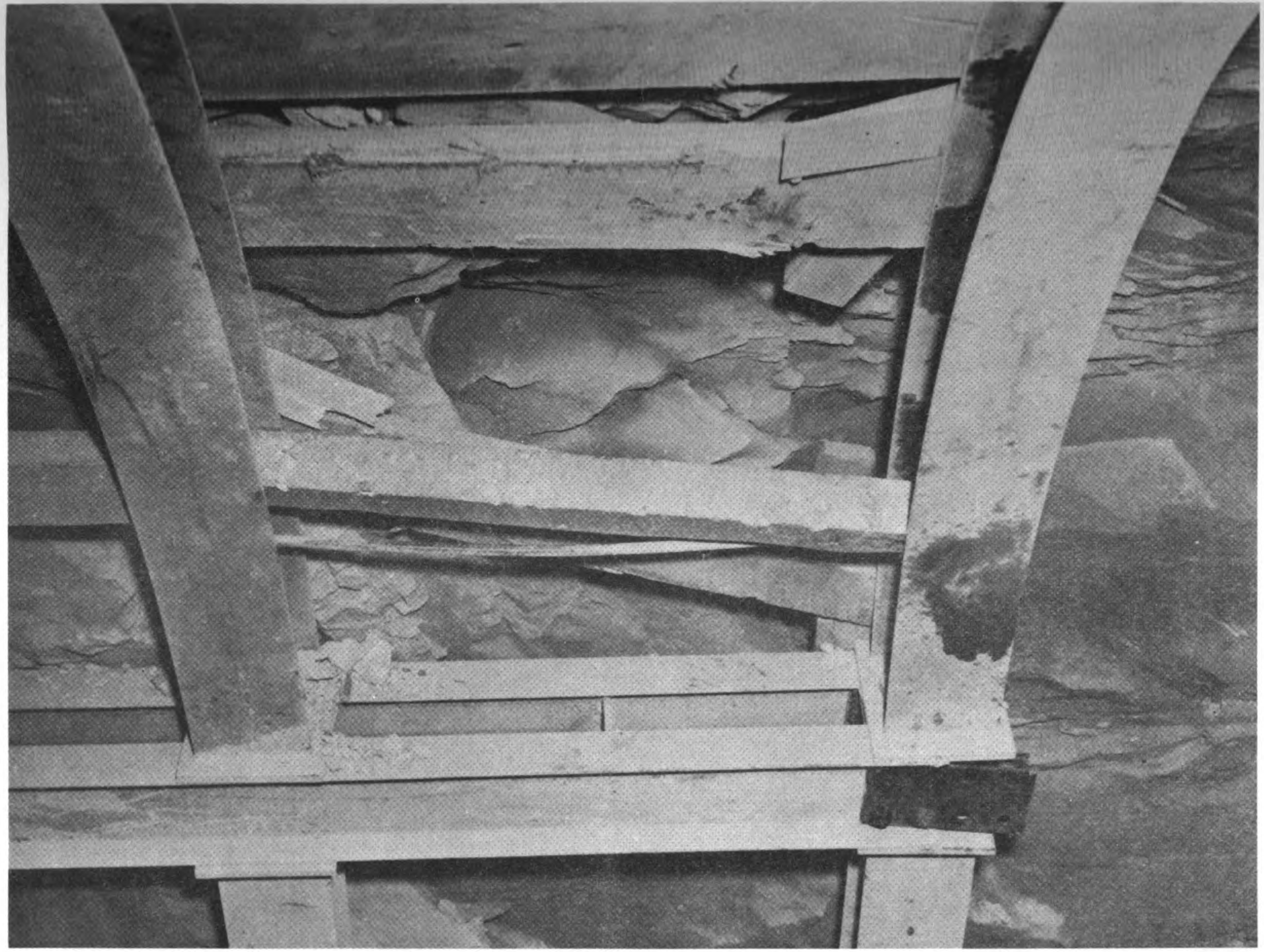

Figure 7. - Wall plate, showing splice bars.

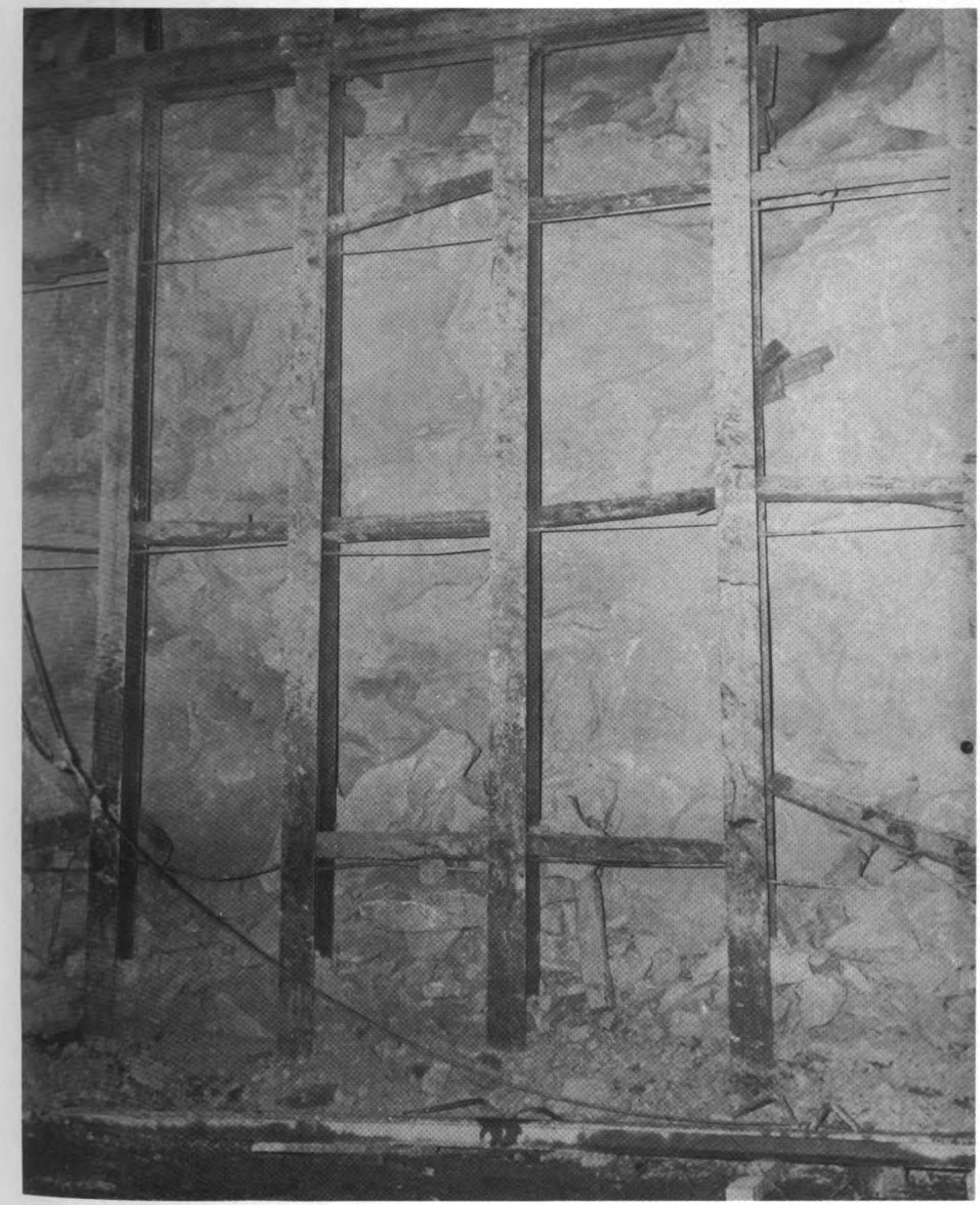

Figure 8. - Plumb post supports with separators; gantry rail shown at bottom.

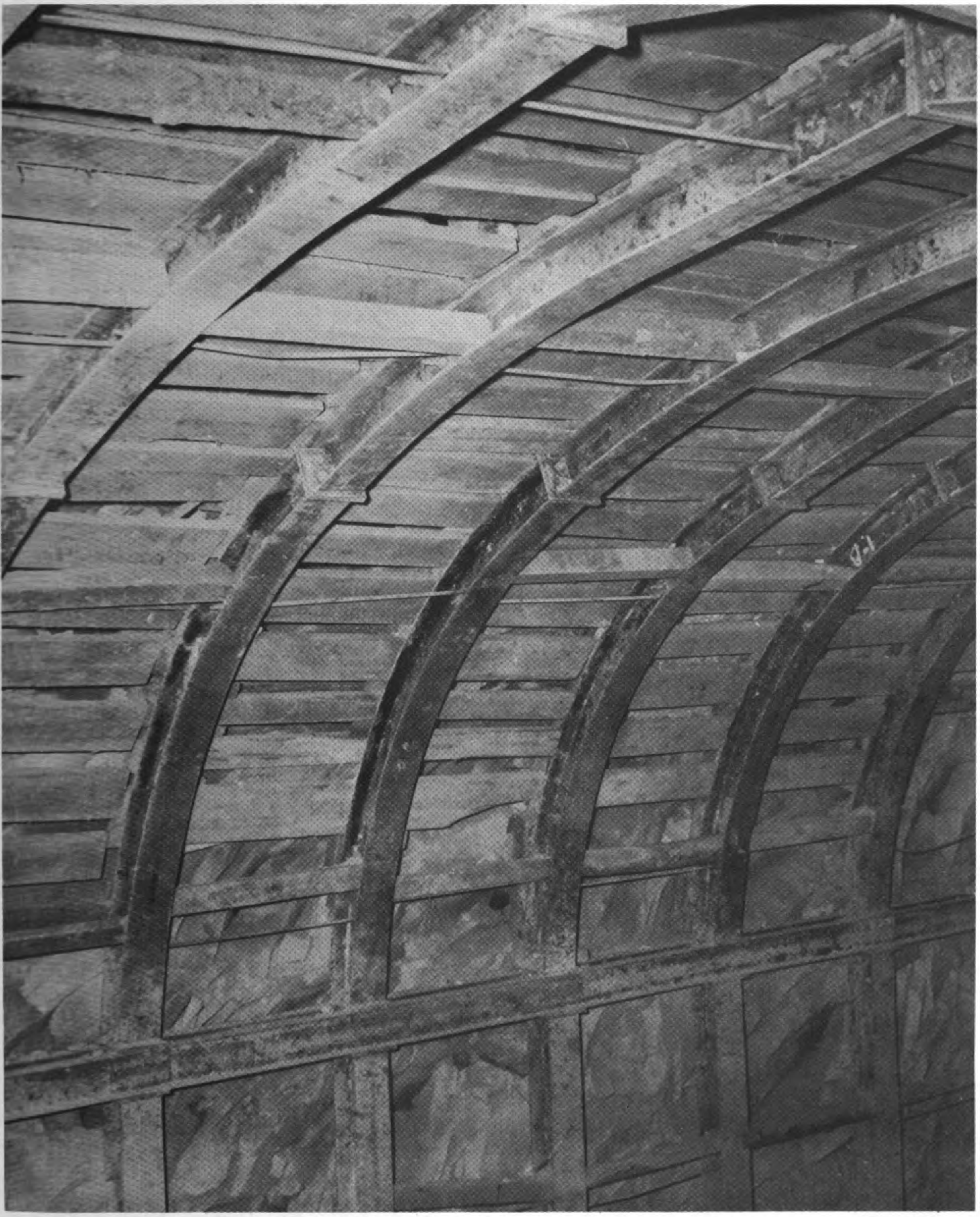

Figure 9. - Steel arches, wall plate, and plumb posts, showing 4- by 4-inch wooden and ¾-inch steel separators.

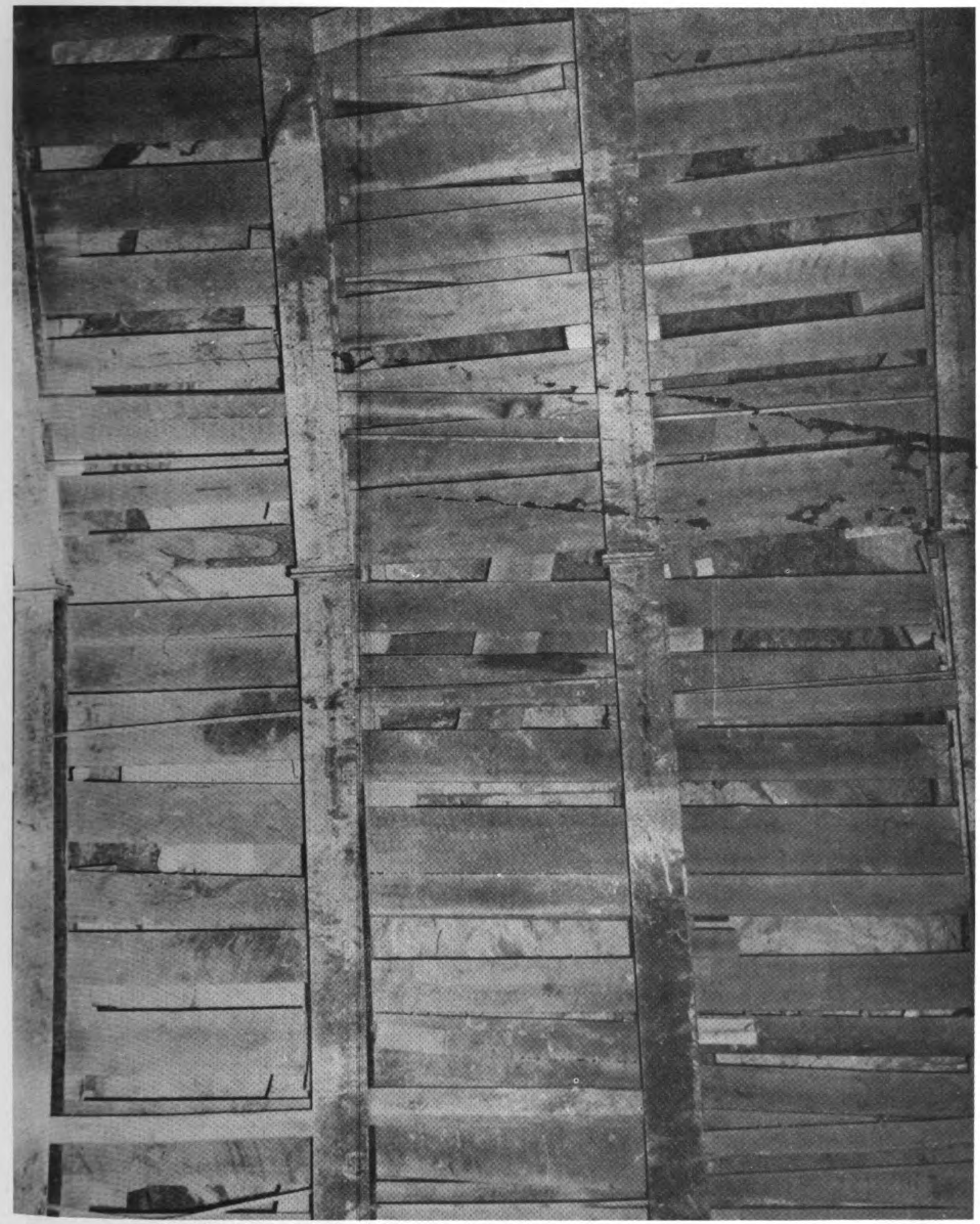

Figure 10. - Properly blocked lagging over steel arch ribs.

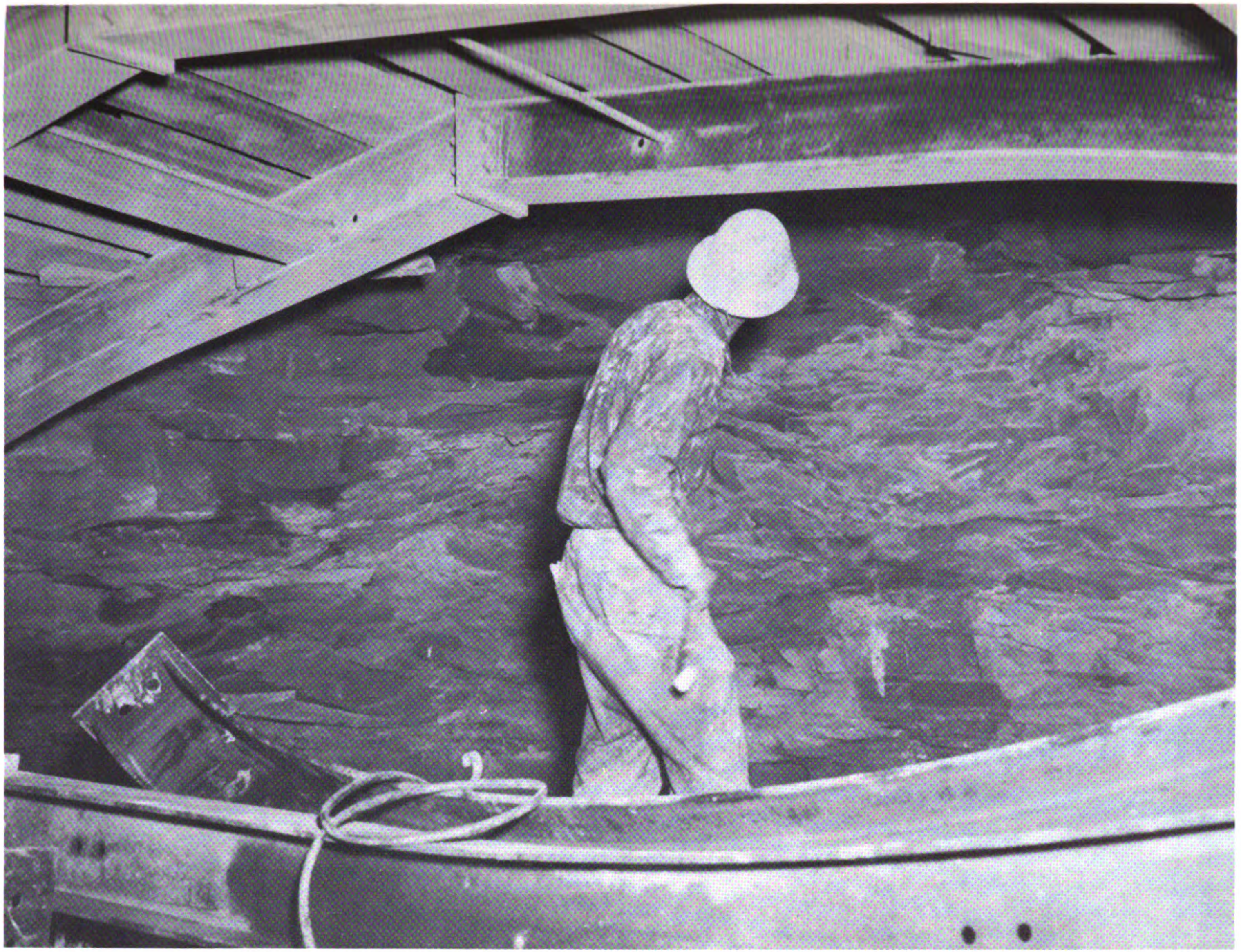

Figure 11. - Workman scaling roof and face from top of jumbo. Note crown bolting.

tunnel, pushed the "fly rock" to the foot of the muck pile (material displaced by the blast), thus clearing the floor and shaping up the muck pile, and then left the tunnel. A 1-1/2-yard electrically operated shovel (fig. 3), later replaced by a 1-1/2-yard Diesel-powered shovel, was then moved up to the muck pile, and the displaced rock was loaded into three 10-cubic-yard Diesel-powered trucks and removed from the tunnel.

The trucks were driven into the tunnel near the shovel, where a steel plate about 20 feet long, 10 feet wide, and 3/8 inch thick on the floor of the tunnel was used as a turntable for the trucks to assist them in backing up to the shovel. The plate was coated with grease, and a pneumatic tugger hoist was installed nearby. The front wheels of a truck were angled onto the steel plate, the rope from the tugger hoist was then fastened to the front axle of the truck, and while the rear wheels remained on the tunnel floor the front wheels were skidded along the steel plate until the truck was in position to back up. The steel plate was moved closer to the tunnel face (heading) as excavation progressed.

No effort was made to scale the roof in the heading while mucking. This was usually done from the jumbo at completion of the mucking. However, on some occasions it was necessary to stop mucking, place the gantry rails, and push the jumbo into the heading to provide a scaling platform (fig. 4). Figure 4 also shows the holed-through pilot tunnel. Owing to the height and width of the tunnel, roof scaling was difficult. After scaling, the jumbo was moved back, and mucking was resumed. Because some of the material had been removed when the pilot tunnel was driven, the muck pile was not high enough to work from, and the width was too great for a staging from wall plate to wall plate; therefore, diverse scaling methods were employed as necessary.

The roof was supported by wooden roof supports during the early stages of construction because of a steel shortage. Each set of timber consisted of a center crosspiece and two side segments set at an angle of approximately 45° on plumb posts (legs) and lagged over the crosspiece with 12- by 2-inch wooden plank (fig. 5). At some places the lagging was placed over the side segments as well as the crosspiece (fig. 6). A lagging failure can be noted in the foreground of figure 5. Timber sets ranged from 5 to 12 feet, center to center.

Wooden roof supports were replaced by steel when steel became available. A steel roof support consisted of double I-beam wall plates (fig. 7) supported by long H-beam (27 pounds per foot) plumb costs with flanges 8 inches wide, placed on 4-foot centers (fig. 8). Ribs (arches) of steel consisting of H beams (40 pounds per foot) with flanges 8 inches wide, made in four segments bolted together, were supported by the wall plates and were placed on 4-foot centers to form arches for supporting roof rock (fig. 9). Separators consisting of 4- by 4-inch wooden collar braces and 3/4-inch round steel rods were placed from arch to arch (rib to rib) and between adjacent plumb posts to act as stiffeners (figs. 8 and 9). Wooden 2- by 12-inch crown lagging was placed over the steel arches at 16 separate places and securely blocked so as to concentrate the weight on the arches (fig. 10). Voids over the steel and lagging were properly blocked. Figure 11 shows a workman scaling the roof and face of the tunnel from the top deck of the jumbo. When enough room is available, the rib sections lying behind the safety miner will be erected, thus bringing support up to the face before drilling is started.

Figure 12 shows the jumbo being placed in position at the face of the tunnel before starting drilling operations. Good roof support at the face also is shown in this photograph.

Figure 13 shows the roof support looking toward the west portal from the midpoint of Saltsburg tunnel; the high platform used for reblocking and straightening lagging is shown at the portal. Figure 14 is looking in the opposite direction from the same point, showing roof support and drill jumbo. The contrast between the wooden and steel roof supports can be noted by comparing figures 13 and 14 with figures 5 and 6.

A centrifugal blower situated just outside the west portal provided ventilation for the tunnel through a 30-inch-diameter steel vent pipe (see figs. 5, 13, and 14), which generally was extended to within 50 feet of the tunnel face (heading). The blower was rated at 12,000 c.f.m. and was arranged to ventilate by exhausting or blowing. Natural draft through the main bore and the pilot tunnel appeared to have some effect on the air movement in the tunnel, and the direction of air movement determined whether the blower was operated exhausting or blowing.

BALTIMORE & OHIO RAILROAD TUNNEL

This tunnel was driven for the Baltimore & Ohio Railroad Co. near Philippi, Barbour County, W. Va., by the Bates & Rogers Construction Co., Chicago, Ill. It was driven as part of an extension of the railroad designated as the Elk Creek spur of the Mongah Division. This spur was constructed to bring railroad facilities to undeveloped coal fields north and west of Philippi between the towns of Berrysburg and Overfield.

The direction of the tunnel was approximately east-west. Driving was done from the west portal, the elevation of which was approximately 1,040 feet above sea level. The grade of the tunnel is 1.5 percent ascending from west to east. The tunnel is a single-track project and was lined with concrete for its entire length of 1,500 feet; the dimensions in the rough were 24 feet wide by 34 feet high to an arched roof. After lining, the inside dimensions of the tunnel were 18 feet wide, 28 feet 6 inches high to the crown, with a uniform 9-foot roof radius from the "springing line," which is 19 feet 6 inches above the tunnel floor.

An interesting feature of this tunneling operation is that the bore pierced an abandoned portion of a mine in the Pittsburgh coal bed. The coal bed is about 10 feet thick, starting at approximately 15 feet above the tunnel floor, and persists for the length of the tunnel. The coal bed lies between friable fire clay. According to a map of the mine, 22 mine openings were crossed by the tunnel. (The method of closing off the old mine workings is described in a later section.)

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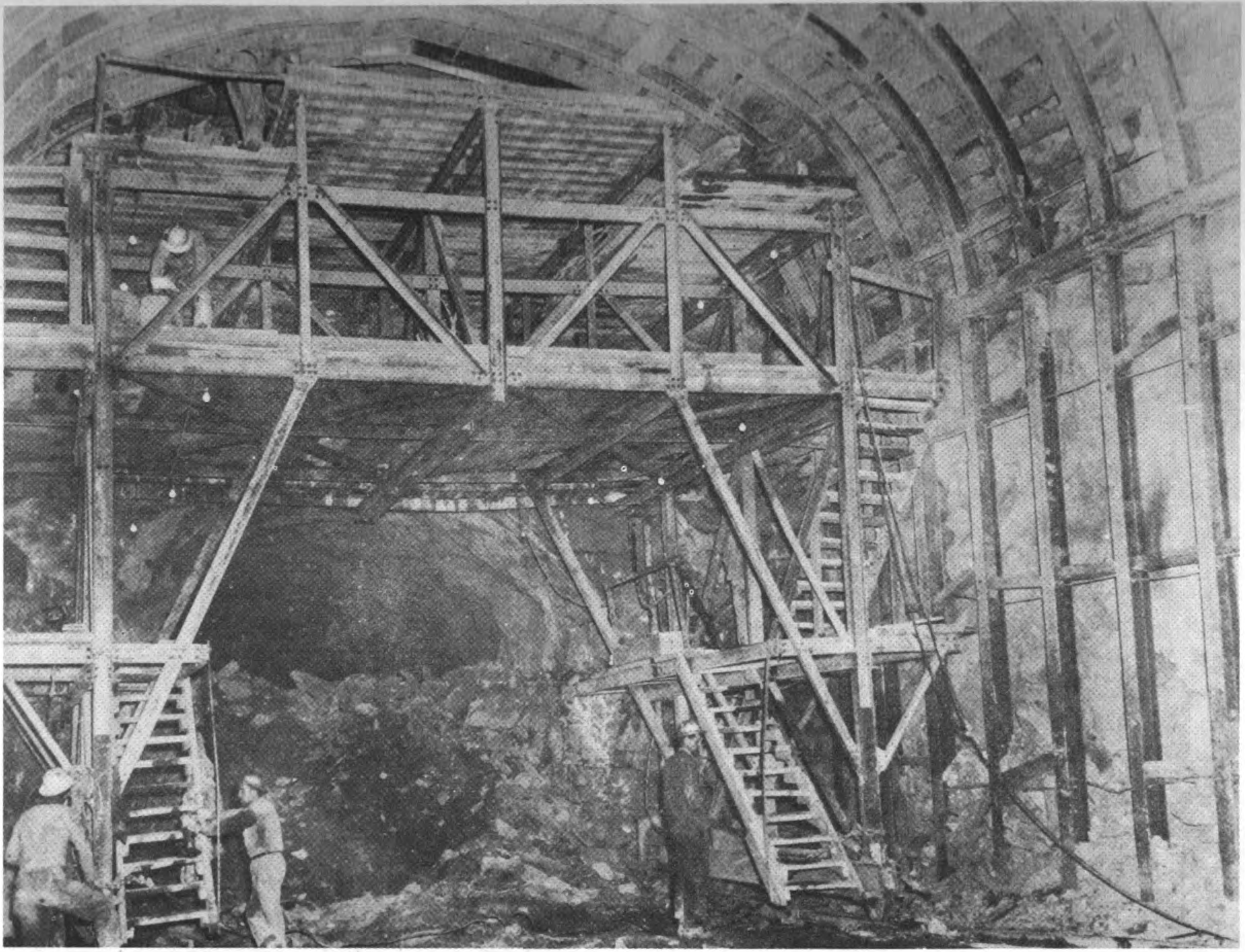

Figure 12. - Drill carriage (jumbo) at face of tunnel.

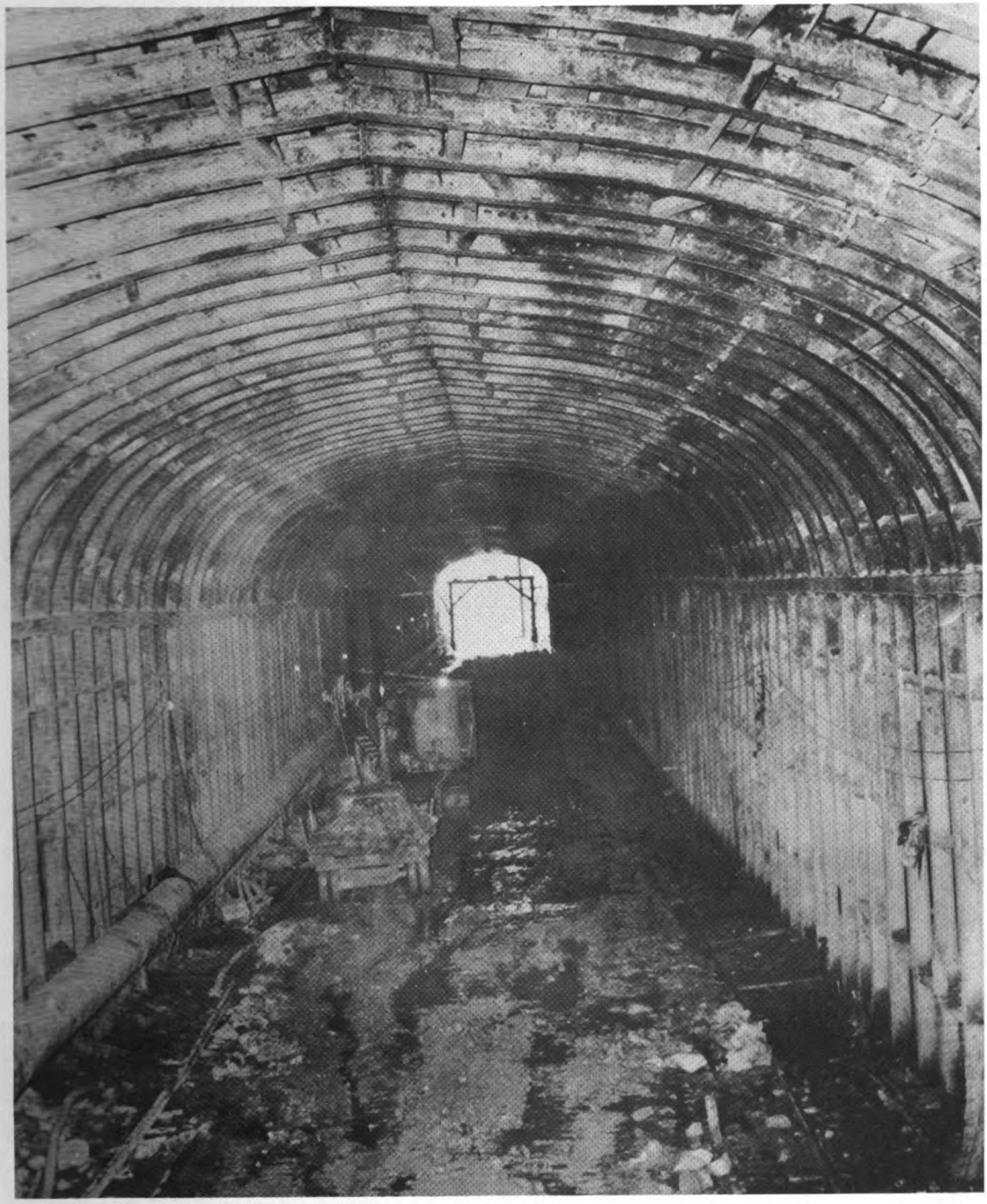

Figure 13. - Looking toward west portal from midpoint of Saltsburg tunnel. All wooden supports replaced by steel.

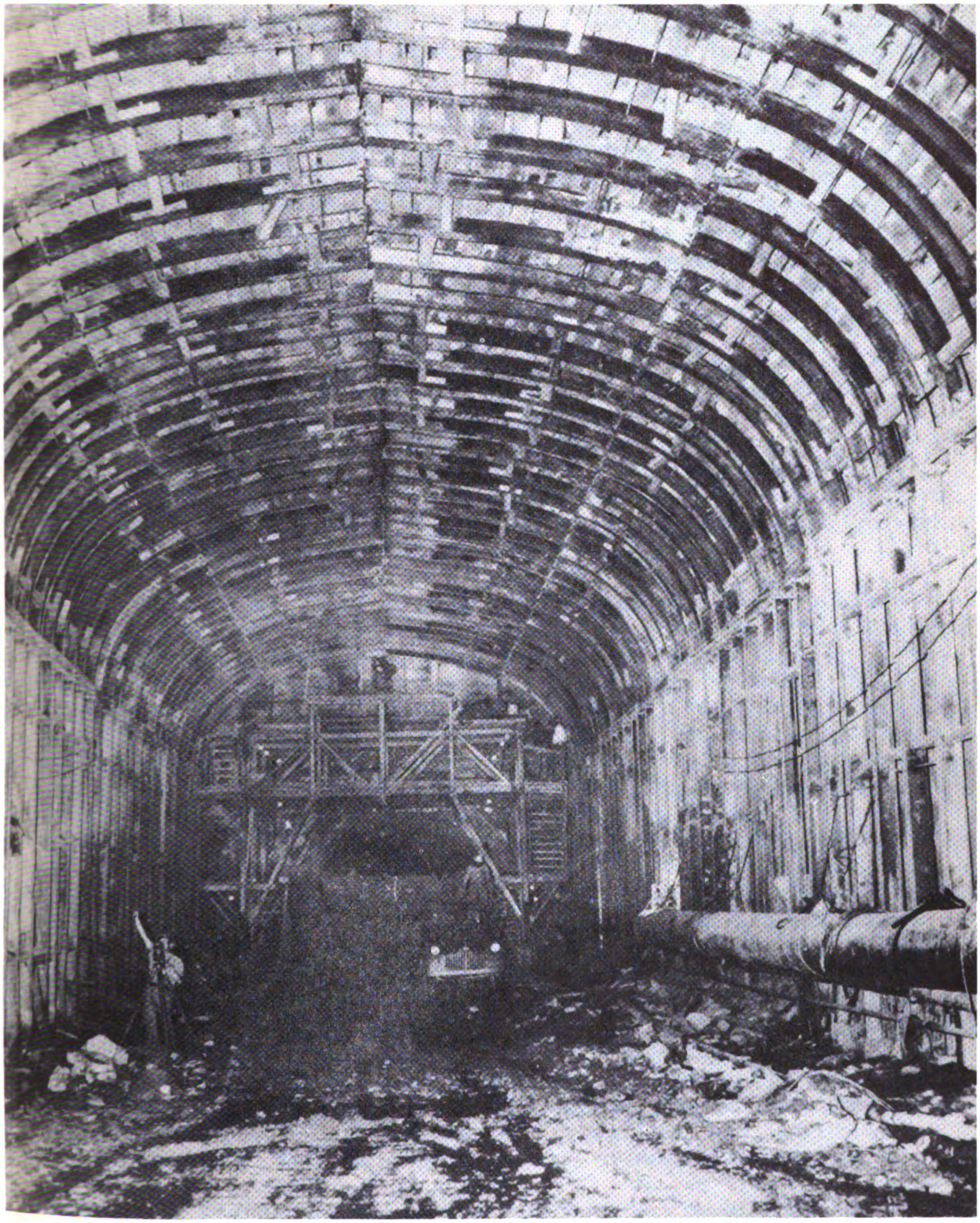

Figure 14. - Looking east from midpoint of Saltsburg tunnel.

Temporary buildings on the surface provided repair-shop, storage, and office facilities. Six portable, Diesel-powered, two-stage air compressors were housed in one building. The compressors were connected to a common manifold and operated automatically, so that one cut in or out according to compressed-air requirements.

Tunnel ventilation was provided by a 2- by 4-foot centrifugal fan driven by a 50-horsepower, 440-volt, a.c. motor operating at 1,150 r.p.m. under full load. The fan was said to have a rated capacity of 13,000 c.f.m. and delivered air to the tunnel portal through a 30-inch steel pipe. From the portal, the air was conducted to the tunnel face through 24-inch, rubberized-fabric, collapsible tubing suspended along the left wall of the tunnel. With such tubing the fan could be operated blowing only. During the author's visit to the tunnel, the fan was stopped approximately 2 hours after blasting and was not operated during mucking.

The batteries of the two battery-powered locomotives were charged in a small building on the surface and were connected to the charging plug at every opportunity when the locomotives were not operated.

The "drill doctor," who kept the pneumatic equipment in operating condition, shared the shop building with the general repairmen. Pipe work and welding also were done in this shop.

Steel and wood were used to provide roof support. The steel roof support, consisting of 8-inch H-beams weighing 34 pounds per foot, differed in design from the type generally used in tunnels; it was designed in two sections, each resting on a mudsill and joined by bolts at the crown. The sections, which comprise the combined column and half of the arch, were 19 feet 6 inches long from the base to the springing line, from which they curved on a radius of 10 feet 2 inches for an arc of 90°. Two 8-inch I beams, set 4 inches apart and connected by web plates welded to each beam, were used as mudsills. One-inch round steel tie rods and 4- by 4-inch wooden collar braces also were used between the ribs of steel. The sides below the springing line generally were lagged with wooden planks placed "skin to skin." It was intended to use these planks as inside forms in concreting operations. The arch above the springing line was lagged solid with one of two types of steel sheet used as "wet" or "dry" lagging and according to the condition of the tunnel. The dry lagging was in the form of a shallow pan 40 inches long, 16 inches wide, and with 1-1/2-inch flanges on the sides. The flanges were set on the inside of the steel (top flanges), and adjoining pans were bolted to the sides of the flanges. The wet lagging was of special design furnished by a commercial shearing and stamping company; it was 5 feet long, 1 foot wide, and had corrugations approximately 4 inches wide. The wet pans overlapped, and lagging was used where water from the abandoned coal mine entered the tunnel.

The method of roof support was as follows: The mudsills were set on each side, and the steel ribs were pulled into place with an air hoist (tugger) mounted on the jumbo. Double snatch-block pulleys, attached to a boom projecting from the jumbo and the last bent of roof support, were used in the operation. The steel was pulled into position, bolted at the

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crown and mudsills, secured with the tie rods and collar braces, and blocked before the lagging was placed. The jumbo furnished the necessary footing during this operation. At the time of the visit, the steel roof support was erected 8 to 10 feet from the face before blasting. This was the general rule during excavation.

The entries of the abandoned coal mine were "mucked out" to the angle of repose of material consisting of gob, fallen roof rock, decayed timber, and other debris. Cribbing was then erected to prevent slides and falls of roof in the entries, and wooden bulkheads were built to provide inside forms for the concrete seals that were constructed to close off the entries. The seals were necessary to prevent the concrete, which was placed pneumatically when the tunnel was lined, from spreading into the mine workings. The seals provided part of the inner forms for the finished tunnel lining. Dry packing with large pieces of rock recovered from the muck pile was used to fill the voids behind the plank lagging where necessary. This was done manually from platform staging. Twenty-two abandoned coal-mine entries were crossed during the excavation. These entries presented a problem, because the floor of the tunnel was approximately 15 feet below the floor of the coal bed, necessitating working platforms, which were placed on brackets set between the sidewall lagging. The material used for cribbing and filling was passed by hand from the tunnel floor to the working platform and in some places passed from a lower to an intermediate platform, and was then placed behind the lagging.

Drilling was done from the jumbo, which was mounted on double-flanged wheels resting on 11-foot-gage gantry tracks. Eleven water-lined drifters were mounted on the jumbo in the following positions: Two for drilling lifter holes, two each on the first and second wings, three on the top wings, and two on the top deck. All drills were connected to manifolds for air and water. Drilling was not difficult in this tunnel, because the strata penetrated consisted of the soft rock formations, mostly shale, clay, and coal. Ordinarily, the bottom part of the tunnel was in softer rock than the top. A full 10-foot cut was drilled in approximately 1-1/2 hours. Hollow, round drill steel with detachable bits was used. Sixty-five to seventy holes were drilled for each round. Water for drilling was obtained by pumping trapped seepage from the mine workings.

Blasting was done with a 65-percent-strength semi-gelatin explosive of medium speed and density. Explosives were brought into the tunnel as needed from storage magazines on the surface and were hauled on a flat car pulled by a battery locomotive. The explosive was somewhat plastic and had good water resistance and fume rating; it was fired with electric delay detonators (1 to 7). Charges were stemmed with loose bulk earth. A fixed shot-firing circuit carrying 440 volts alternating current was used to fire all detonators, which were connected to it through a portable firing cable. All firing was done from the outside at the west portal. Approximately 400 pounds of explosives were fired in a full-face 10-foot round.

The ventilation was induced as previously described. Sometimes, the fan was not operated during mucking, with the result that air movement from the tunnel into the mine workings was sluggish. Smoke from blasting was not evident, and only an occasional odor of fumes could be noticed during

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mucking when the fan was shut down for as long as 2 hours after blasting. Liberation of methane was reported during operation of the now abandoned mine. For this reason, a West Virginia certified fire boss examined the tunnel with an approved-type flame safety lamp after each blast. Thus, some protection was provided against the hazard of methane that might have entered the tunnel from the mine workings. This hazard would have been greater if atmospheric conditions had been such that the natural movement of air was from mine workings to tunnel, rather than the reverse.

A mucking machine powered through a trailing cable was used to load mechanically. This machine, a combination shovel and belt conveyor, was used to load the excavated material into 5-cubic-yard, side-dump muck cars. The muck pile was thoroughly wetted with water. From advantageous positions on the muck pile and in the open mine entries, safety men scaled loose roof material constantly with long scaling bars during the mucking period.

A "cherry picker" built into the jumbo was used for car changing; it was powered by a tugger-type air hoist. Two double pulleys (closed snatch blocks) and a cross bar were used to raise an empty car high enough to clear a loaded car being pulled away from the mucking machine. Bridle chains from the cross bar were fastened to each corner of an empty car that was being elevated. The up grade and the wet condition of the track and muck pile made mucking rather difficult and required sanding of the track rails. The mucking machine was not equipped with sand boxes; therefore, the cable tender sanded the rails by hand with sand from a shovel.

All underground hauling was done with two storage-battery locomotives on a track of 36-inch gage. The loaded mine cars were hauled out of the tunnel and dumped on the spoil bank on the surface.

EAST BRANCH TUNNEL

The East Branch tunnel is part of the outlet works, East Branch Dam, Clarion River, Pittsburgh Flood Control, and is about 7 miles north of Johnsonburg, Pa. The work was done by Hunkin-Conkey Construction Co. and Shofner, Gordon, & Hinman, contractors, under the direction and supervision of the U. S. Corps of Engineers, Pittsburgh District. The tunnel was driven from the downstream portal on an upward grade of 0.5 percent. The length was approximately 1,250 feet, and the cross section was circular. The diameter of the rough excavation was 14 feet, and, after lining with concrete, the finished tunnel was 10 feet in diameter. The alinement of the tunnel included two 350-foot and one 250-foot radius curves. Excavated strata consisted of shale, sandstone, and limestone, which was sometimes fossiliferous. The strata were loosely bedded at the portals but were firmer as the cover increased.

Excavating and subsequent concreting operations in this tunnel were accomplished without a lost-time accident; as many as 50 men were employed on the project. This is an extraordinary record, and all persons connected with the project should be commended highly for the accomplishment.

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Steel and wood were used to provide roof support. Wood was used for lagging and blocking, and the quantity used depended on the condition of the strata. Each steel ring, circular in shape, was designed in three sections, which were bolted together. These steel ribs were constructed of H-beams with flanges 6 inches wide and weighing 16 pounds per foot. The crown of the support was raised slightly to form a tear-shaped opening. The inside diameter of the steel rings was 12 feet, and 1-inch round steel was used as tie rods between the rings. The face of the steel was 1 foot inside the concrete lining when the tunnel was completed. A total of 488 rings of steel was placed and spaced at distances ranging from 15 to 36 inches apart, depending on roof conditions. The total weight of the roof-support material was approximately 378,000 pounds.

Figure 15 shows the outlet portal of the tunnel, collapsible ventilation tubing, and compressed-air line.

Figure 16, looking from the outlet portal toward the inlet portal, shows the steel roof support, mine tracks, pipe lines, and tunnel illumination.

Figure 17 shows the interior of East Branch tunnel looking from the inlet portal toward the outlet portal; in the background is the platform used for straightening and tightening roof supports and blocking.

Drilling was done with four water-lined drifters supported on a track-mounted (36-inch gage) jumbo. Air and water connections to the drills were from manifolds built into the jumbo. Hollow round drill steel with detachable bits was used. The length of the starting steel was 2-1/2 feet, and each succeeding drill steel was in increments of 2 feet. The condition of the rock determined the number and length of the drill holes; generally, however, 40 holes 5 to 9 feet in length were drilled for each round. Compressed air was generated on the surface by two compressors and transmitted into the tunnel through a 4-inch steel pipe line. The connection between the inby end of the air-line and the jumbo was made by means of a rubber "bull" hose.

Blasting was done with a 40-percent-strength gelatinous explosive, and the charges were stemmed with clay. The explosive charges were fired with electric delay detonators (1 to 5) connected to a 220-volt, alternating-current, shot-firing circuit. The quantity of explosive per round ranged from 85 to 120 pounds, depending on the number and length of the drill holes and the nature of the rock.

Ventilation was induced by means of a blower fan situated outside the portal, which forced air through canvas tubing (shown in fig. 15).

The tunnel was illuminated by electric lights suspended along its length.

Mucking was done with a 1/4-yard pneumatic shovel that loaded into 2-yard, sidedump, mine cars. As the tunnel was of small bore, only a single 36-inch-gage track could be installed for haulage, and car changes were made with a pneumatic "cherry picker," which lifted an empty car off the track and allowed

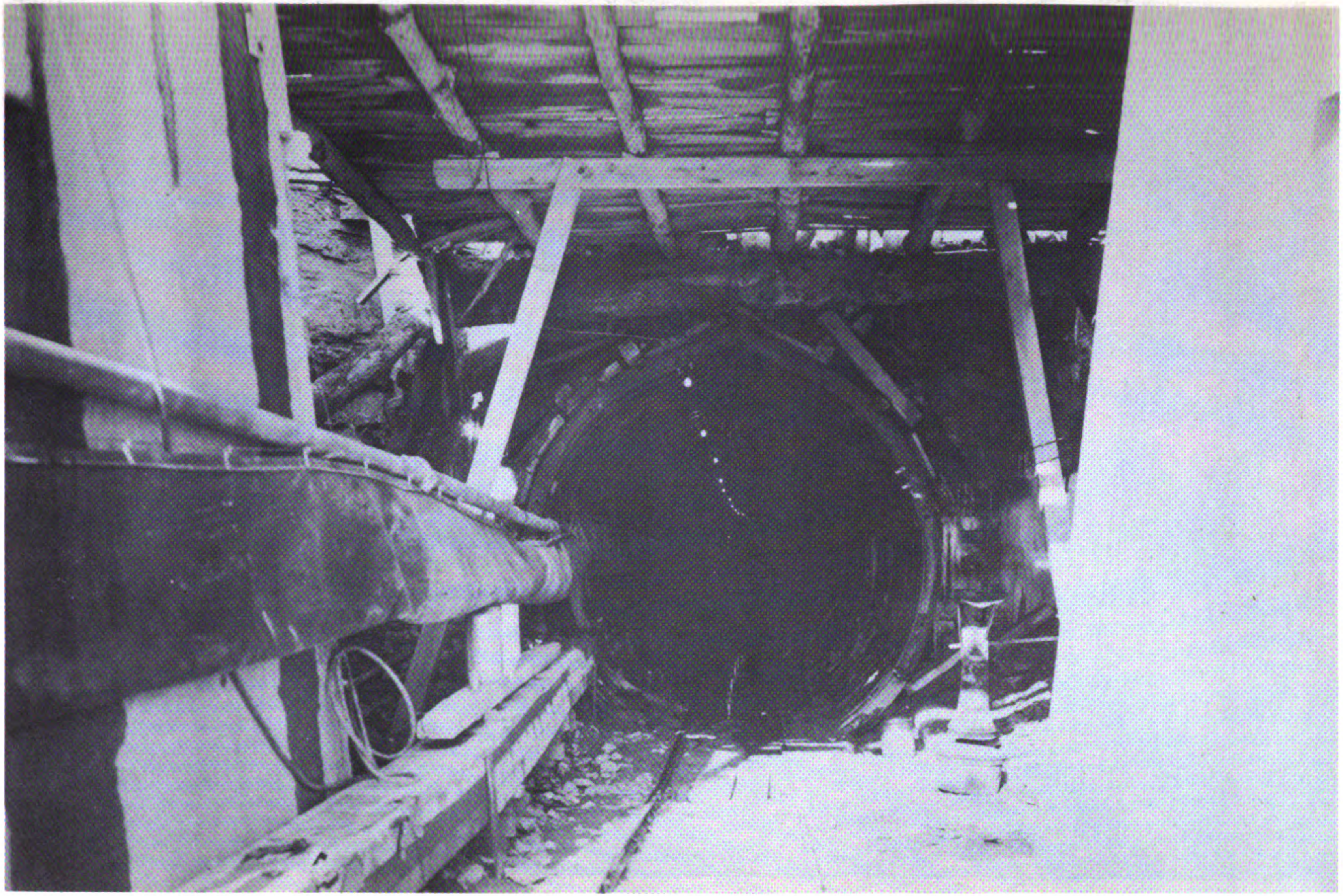

Figure 15. - Outlet portal, East Branch tunnel.

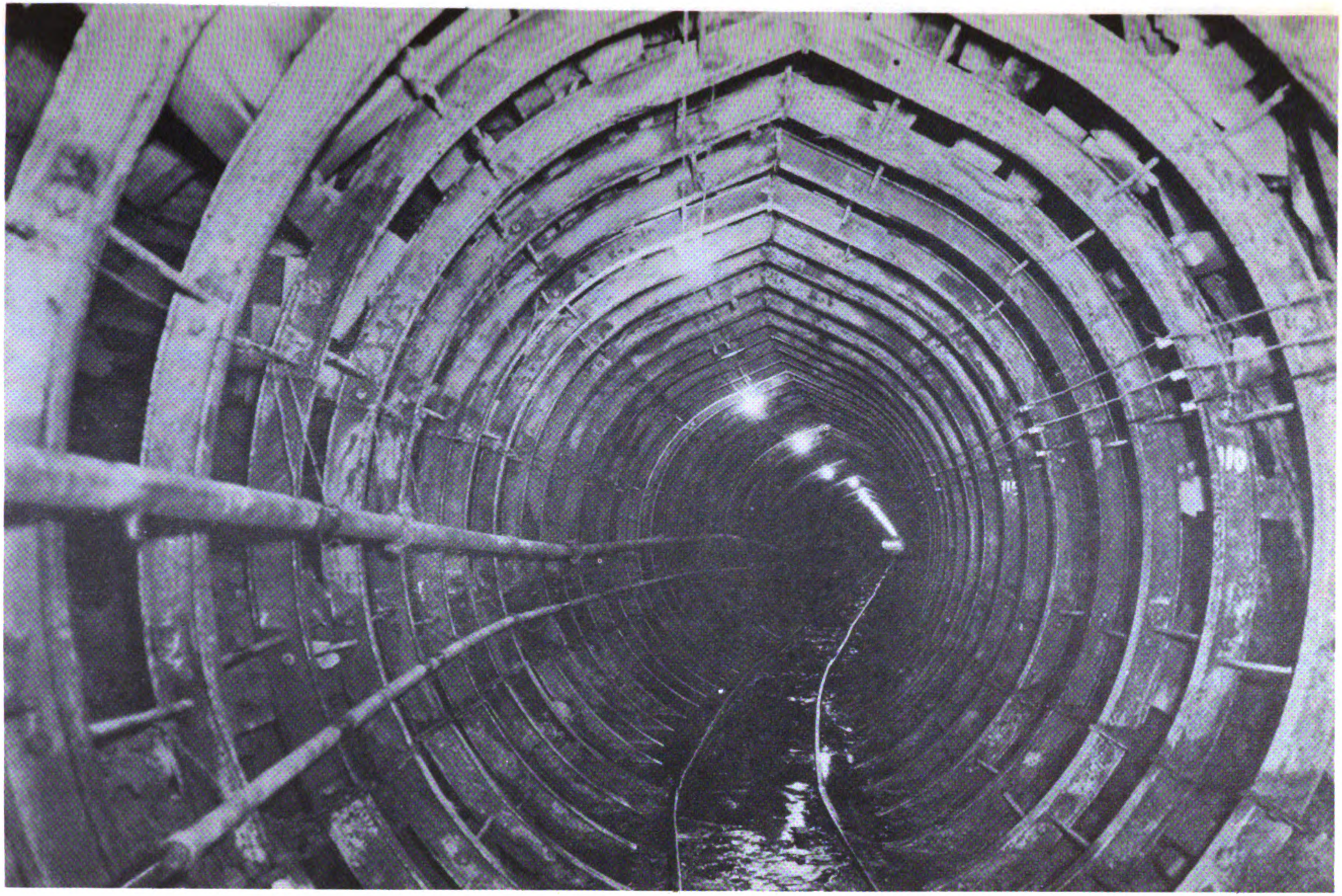

Figure 16. - Looking from outlet portal toward inlet portal, East Branch tunnel.

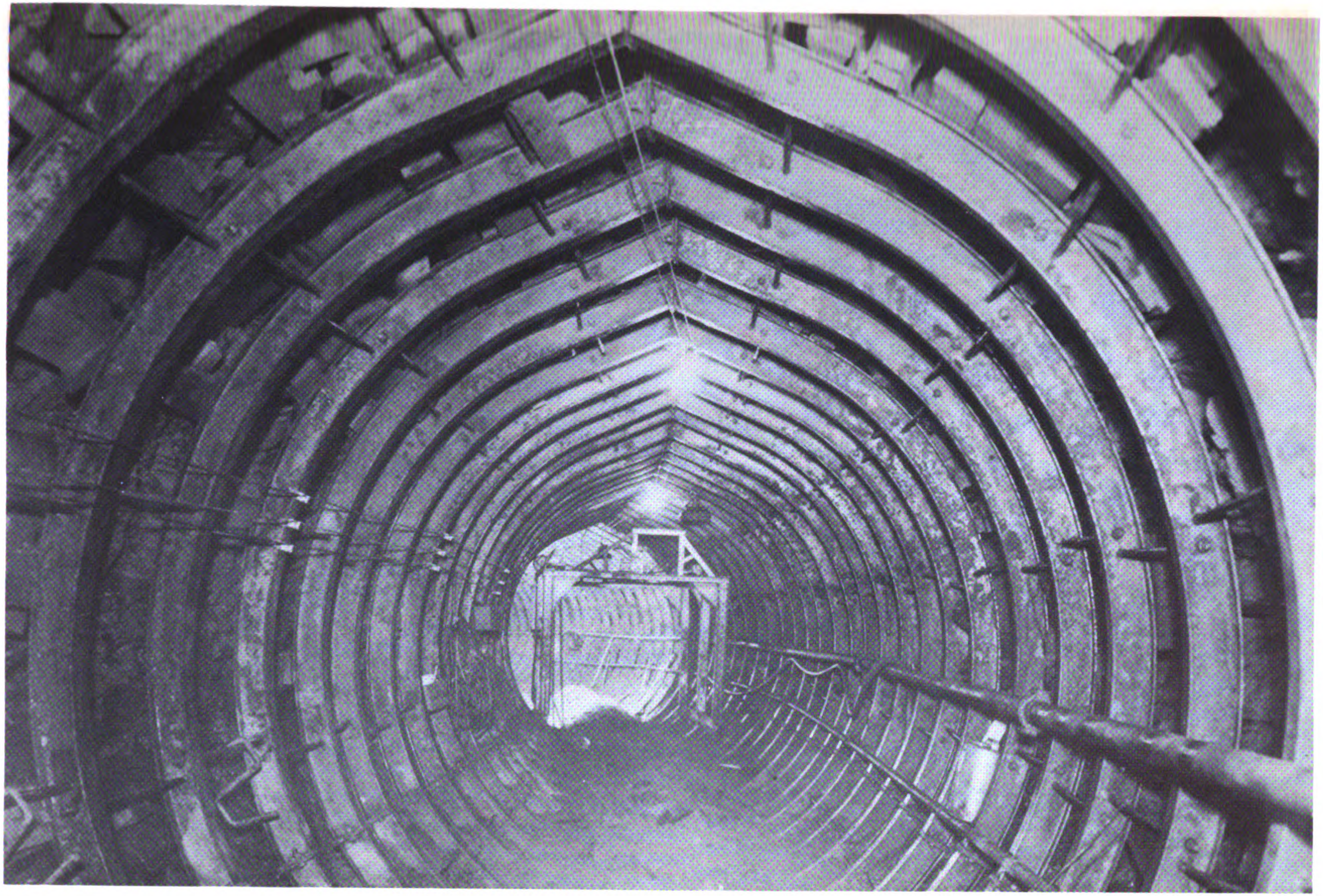

Figure 17. - Looking from inlet portal toward outlet portal, East Branch tunnel.

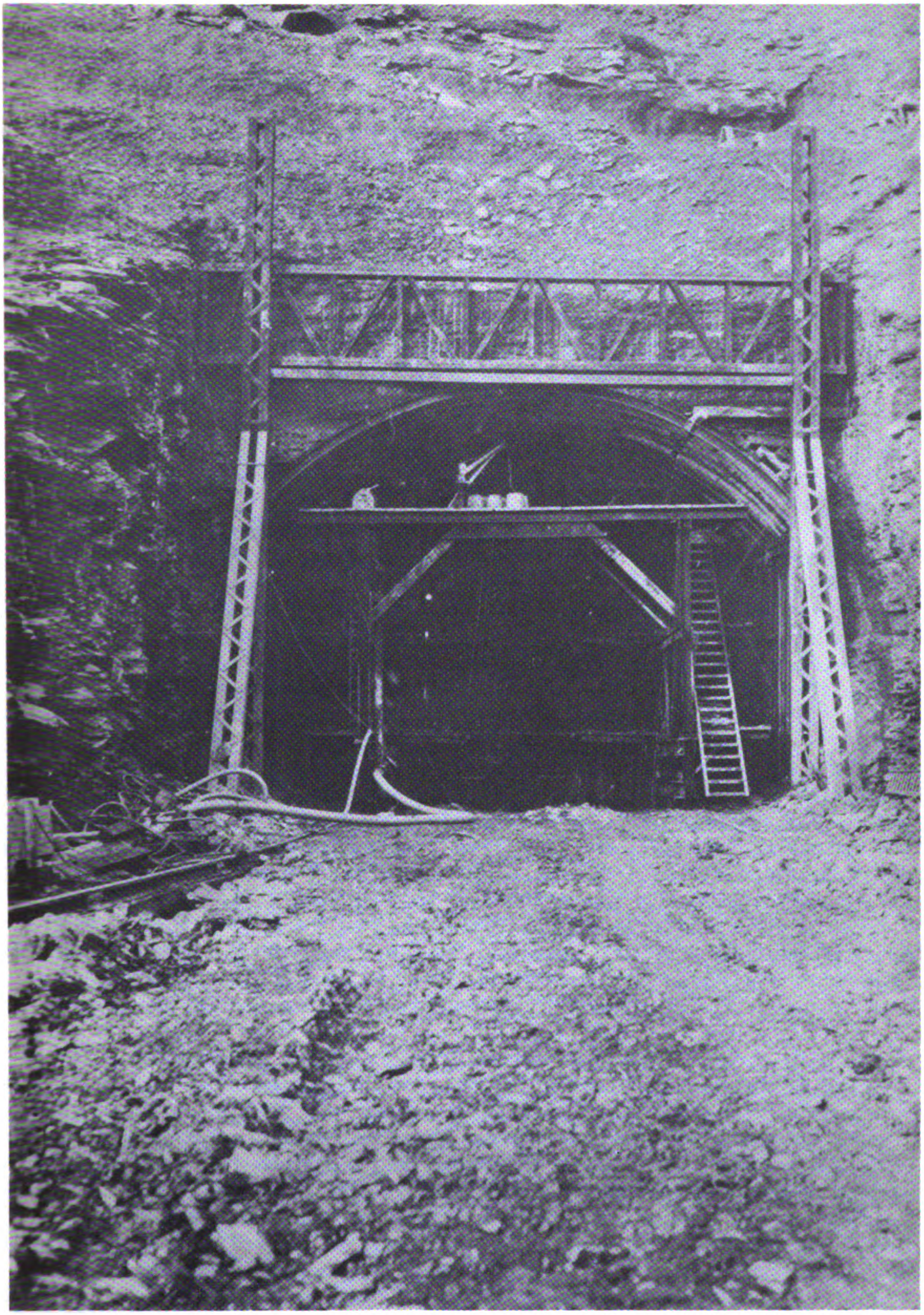

Figure 18. - East portal, north tunnel, showing jumbo, roof support, and high-wall slide barrier, Penn-Lincoln Parkway tunnels.

a full car to be pulled out beneath it, after which the empty car was lowered to the track and pushed to the mucking shovel. A Diesel-powered 6-ton locomotive was used for haulage in the tunnel.

Work on the tunnel was started on December 1, 1948, and it was "holed through" on March 25, 1949. Two 8-hour shifts were worked daily, and excavating progressed as follows: December, 175 feet; January, 333 feet; February, 375 feet; and 356 feet for 25 days in March.

PENN-LINCOLN PARKWAY TUNNELS

The Penn-Lincoln Parkway tunnels were constructed by B. Perini & Sons, Inc., Assoc., for the Commonwealth of Pennsylvania Department of Highways at Pittsburgh, Pa. When this circular was prepared, the excavation had been completed and the concrete lining was being placed.

The tunnels, flat-arch modified horseshoe in shape, were excavated from the east to west portals. It was originally intended to drive the tunnels simultaneously from both east and west portals, but this plan was abandoned. Twin tunnels approximately 36 feet wide, 3,800 feet long, 30 feet high, and 60 feet center to center were driven on a 2-1/2-percent upward grade. Crosscuts 9 by 11 feet were driven through the 25 feet of rock between the tunnels; the first and last of these were approximately 300 feet from the east and west portals, respectively, and the intervening crosscuts were approximately 500 feet apart. The crosscuts facilitated ventilation and were available as escapeways during excavation; they will be maintained for intercommunication when the tunnels are completed.

The excavated strata consisted primarily of shales, the first layer of which was gray shale averaging 12 feet in thickness. This was overlain by 10 to 12 feet of red shale, then about 4 feet of conglomerate and 20 feet of gray shale. Limestone appeared as top rock in only two instances during excavation. Generally, a sandstone formation was 15 to 20 feet above the top of the excavation, which caused the contractor to shorten the drilling depth from 8 to 4 or 5 feet to reduce the amount of explosives in each round and expose less unsupported roof surface. After blasting, the shale was generally badly shattered for considerable depth along the roof and sides, requiring much scaling to remove loose material.

A well-constructed triple-deck jumbo on a 20-foot center-to-center gantry track was used as a platform for drilling and in erecting roof supports in each tunnel. The gantry rails were laid on 8- by 10-inch wooden ties placed longitudinally and braced against the sides of the tunnel. The inby end of the drill carriage projected 9 feet beyond the wheels, thereby eliminating the necessity of advancing the gantry rails to the tunnel face before the roof supports were installed. Ten automatic-feed, water-lined, pneumatic drills were mounted on the jumbo in the south tunnel. The jumbo in the north tunnel (fig. 18) had 14 to 16 pneumatic drills of the same type. Detachable bits were used in conjunction with round hollow drill steel. The starting drill steel was 4 feet in length, and each subsequent one was 4 feet longer. The drills on the top deck of the jumbo were mounted on hydraulically operated, movable, cantilever mountings similar to those on drill trucks in modern mechanized coal mines. The remaining drills were mounted on horizontal and vertical pipe columns attached to the jumbos.

The entire cross section of the tunnel was drilled (full face excavation). Generally, 114 8-foot holes were drilled; however, as previously mentioned, owing to the adverse roof conditions the drilling depth was reduced to 4 or 5 feet and sometimes even less. Approximately 500 pounds of a 40-percent gelatinous explosive were used per round and primed with electric delay (0 to 13 for rounds with 8-foot holes) detonators with 16-foot enameled copper leg wires. The quantity of explosive for rounds with shorter holes was reduced proportionately. The primer was generally placed in the back of each hole; that is, the primed cartridge was the first to be inserted in each drill hole. It was reported that sometimes 40-percent explosive was used for the priming charges and 30-percent for the remainder of the charge in each drill hole.

Cartridges of explosives were primed in a make-up house on the surface, a considerable distance from the tunnels, and placed in suitable wooden carrying boxes. Unprimed explosives in the original cardboard containers also were placed in a suitable carrying box and transported into the tunnel in autotrucks. Primed cartridges were carried separately from other explosives on separate trips. Surplus explosives, primed and unprimed, were transported from tunnel to surface in the same manner.

When holes were being charged, energized electric wires were removed from the face region. Floodlights approximately 45 feet from the face provided illumination for the charging (loading) operation. Wooden loading (tamping) sticks were used. A fixed shot-firing circuit was used to fire shots; it consisted of insulated conductors properly installed on insulators on the side of the tunnel opposite the power wires. Bare copper buss wires were installed on wooden pegs at the mouths of drill holes in the face, and the detonator leg wires were connected to them. Insulated lead wires connected the buss wires to the fixed shot-firing circuit. Shots were fired from a point outside the portal. The face of the south tunnel was kept about 200 feet in advance of the north tunnel face, and a movable red-light signal system was installed to show employees the relative position of the north tunnel face and indicate when the north tunnel was about to be shot, thus warning them to retreat to a safe place.

After blasting, the muck pile was "shaped up," and the "fly rock" was pushed back to the muck pile with a bulldozer. One and one-half yard electric shovels were used to load the muck into 10-yard Diesel dump trucks. The muck was hauled out of the tunnel and used as fill for part of the roadway in the vicinity of the tunnel. During the author's first visit, the muck trucks were backed into the tunnel from the portal to the shovel at the face. At this time, the use of skid plates similar to those used in the Saltsburg tunnel, previously described, was discussed with the contractor. As a result, skid plates with a modification that consisted of placing a steel curbing on the edge were adopted; thus, the wheels of the trucks had more contact surface as they were being pulled along the greased plate.

Safety miners (scalers) using long scaling bars stood on the muck pile and pried down loose material from the roof, sides, and face. The scalers sometimes had poor footing, and with a flat, low muck pile (which resulted when the displaced material was spread by the blast) they had difficulty in reaching the apex of the arch. This was generally so when shallow rounds were blasted. The face and ribs were scaled by using the teeth of the shovel bucket; however, the boom was not long enough to permit scaling the arch of the tunnel above the springing line.

Four 750-cubic-foot-capacity, electrically operated air compressors installed on the surface furnished power for drilling. The compressed air was transmitted through 6-inch, spiral-welded, steel pipe lines laid on the floor of the tunnels. A rubber "bull" hose was used to connect the air line to the manifold on each jumbo. Steel water lines also were connected to the water manifolds by rubber hose.

During the early stages of tunnel excavation one 4-foot, multivane, axial-flow fan and 30-inch collapsible tubing were used for ventilation. The fan had a capacity of 80,000 cubic feet of air per minute. As the excavation progressed, five 4-foot, multivane, electrically driven, axial-flow fans were in use. Two of the fans were blowing air into the tunnels through 30-inch tubing, some of which was collapsible and some of rigid steel. The tubing generally was extended to approximately 100 feet from the face of each tunnel. These fans were on movable platforms and were moved forward as crosscuts between tunnels were completed. The remaining three fans were installed vertically, one above the other, at the left side of the south tunnel portal. The opening at this point was provided with a single wooden bulkhead equipped with doors. These fans were arranged to operate either blowing or exhausting. During the author's visits to these tunnels, the fans were operated blowing, and the north tunnel was used as the return airway. An attendant was on duty at the bulkhead doors to open and close them as truck or pedestrian traffic required.

Steel roof supports were erected on 2- and 4-foot centers, depending on the condition of the rock, and kept as close to the tunnel faces as possible before each round was drilled. The steel plumb posts were set on 12- by 12-inch reinforced-concrete blocks of different heights, one block under each post. The steel for the flat arch was fabricated in two sections for each bent and bolted directly to the plumb posts. Thus, each ring was composed of four separate pieces of steel bolted together. The distance from the floor to the crown of the arch was 26 feet, and the plumb posts were 19 feet long. Distance between the faces of opposite plumb posts was 32 feet 10 inches. The plumb posts weigh 31 pounds per foot, and the arch sections weigh 40 pounds per foot. The arch was lagged with 6-inch ship channels, generally clipped 1 foot apart and bolted to the upper flanges of the steel ribs forming the arch; however, in some instances it was necessary to clip the lagging to the lower flanges. Collar braces (stiffeners) of 3- by 3-inch angle iron were inserted and bolted between the plumb posts and between the ribs from bent to bent of steel support. In addition, wooden collar braces were used to provide greater rigidity to the entire roof-support assembly. Wooden blocking and wedges were used to block and fill the voids caused by the overbreak and scaled rock above the steel roof supports. The blocking and lagging often were dislodged by blasting, and a reblocking crew was employed to straighten and replace blocking and lagging; they also tightened loose bolts. The reblocking crew worked from an elevated platform (steel jumbo) on gantry rails. Roof pressure and blasting caused some roof-support rings to "get out of plumb," and such rings were straightened and plumbed. At some places it was necessary to place additional rings of steel between those previously erected, thus reducing the center-to-center distances between the bents. Scalers using long poles were employed to dislodge loose rock resting on the roof supports throughout the length of the tunnels.

Illumination was provided by electric lights strung along the sides of each tunnel. The faces were illuminated by the use of pan lights.

At some places dry packing was used to fill the voids over the roof support and behind the plumb posts. The sides of the tunnel and the roof were weathering, with considerable "sloughing off," which caused much more dry packing, reblocking, and roof support than was anticipated. Part of the tunnel sidewalls were "gunited" to prevent weathering.

A well-equipped, clean, well-heated and lighted first-aid room, close to the portals and constantly attended by a qualified first-aid man, was maintained and was readily available when required.

YOUGHIOGHENY TUNNEL

The Youghiogheny tunnel is part of the outlet works, Youghiogheny River Reservoir Dam, Pittsburgh Flood Control, near Confluence, Pa.; the project was not visited by the author during excavation. The work was done by Herman Holmes under the direction and supervision of the U. S. Corps of Engineers, Pittsburgh District.

The tunnel, circular in cross section, was excavated approximately 23 feet in diameter; the finished diameter was 18 feet after lining with concrete. However, at a point midway between portals a transition section was enlarged to a finished diameter of approximately 21 feet to allow for installation of gates that will regulate the flow of water. The length of the tunnel was approximately 1,800 feet.

Most of the excavated rock consisted of fairly good, grayish sandstone; however, some shale, clay, limestone, and coal, soft to medium hard, were penetrated.

The entire cross section of the tunnel was drilled in one operation (fullface method). A jumbo with nine water-lined pneumatic drills mounted on it was used as a platform for drilling and for erecting of steel roof supports. The jumbo (fig. 19) was moved in and out of the zone of operation on the mine track. Two compressors on the surface provided compressed air for drilling; the air was transmitted into the tunnel through a 4-inch steel pipe line. The final connections between the water and the air pipes and the manifolds were made by means of rubber "bull" hose.

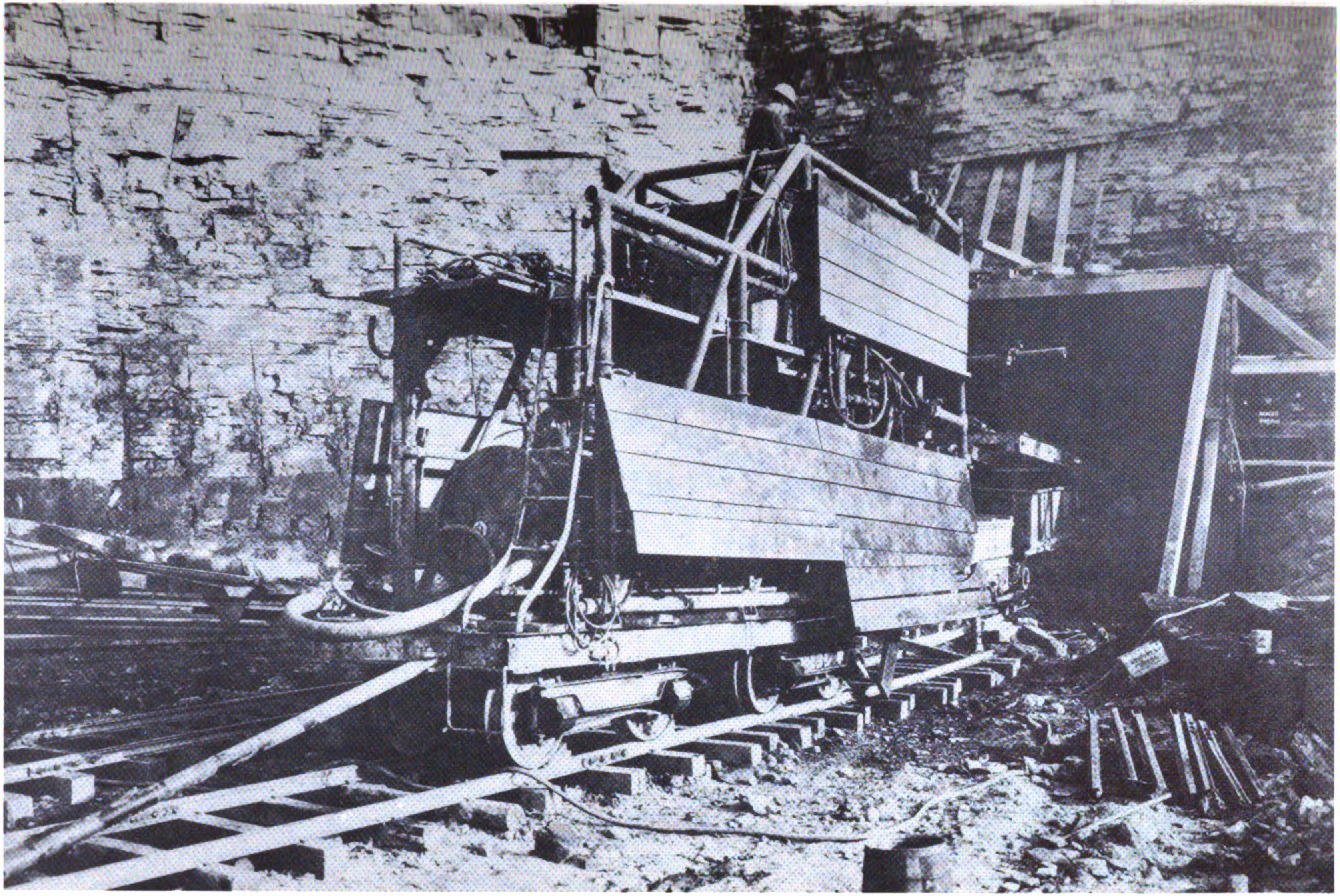

Figure 19. - Drill carriage (jumbo) at portal of Youghiogheny tunnel.

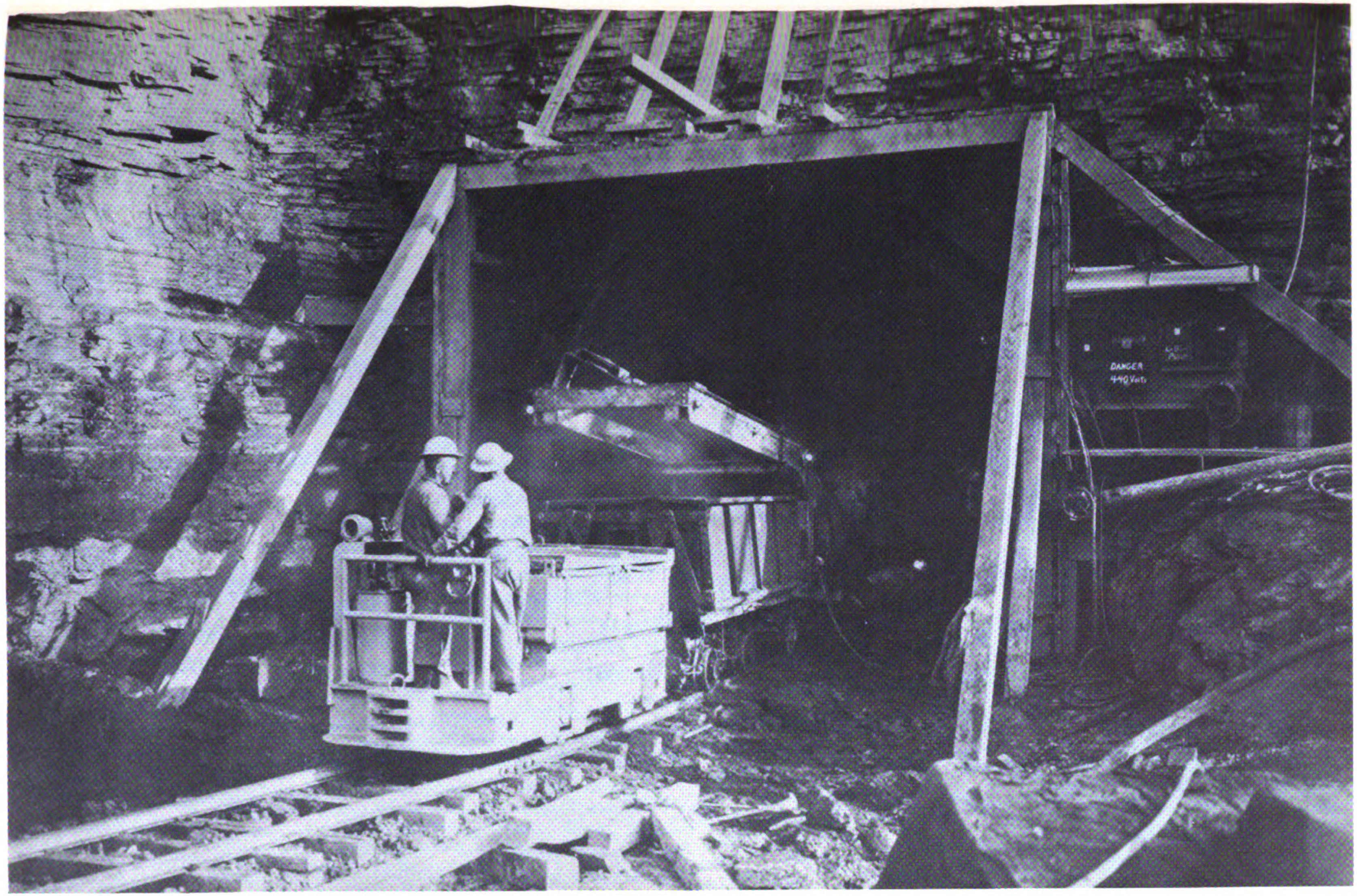

Figure 20. - Battery locomotive, mine car, and scraper-loader at portal of Youghiogheny tunnel.

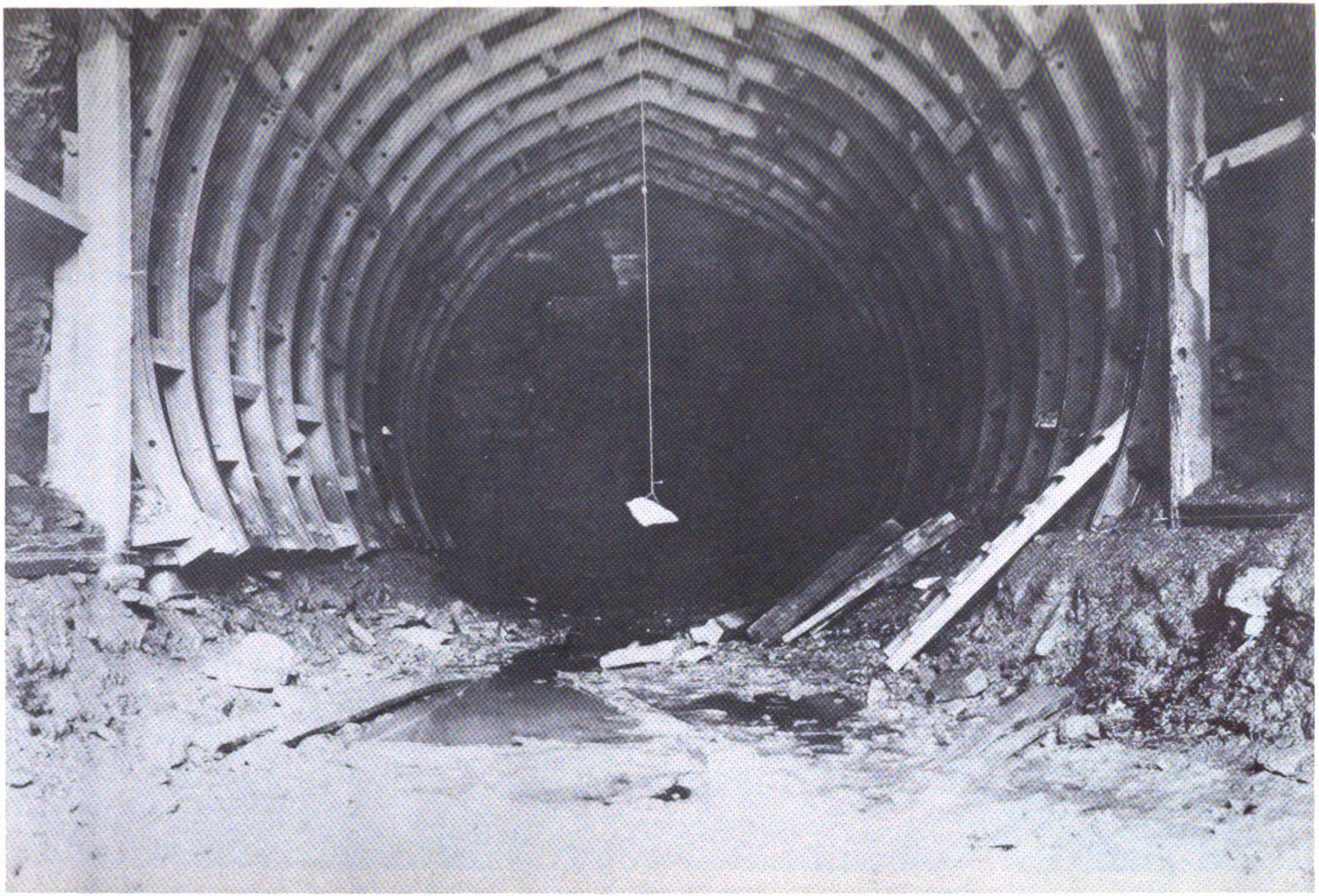

Figure 21. - Steel roof support near portal of Youghiogheny tunnel; invert steel not yet erected.

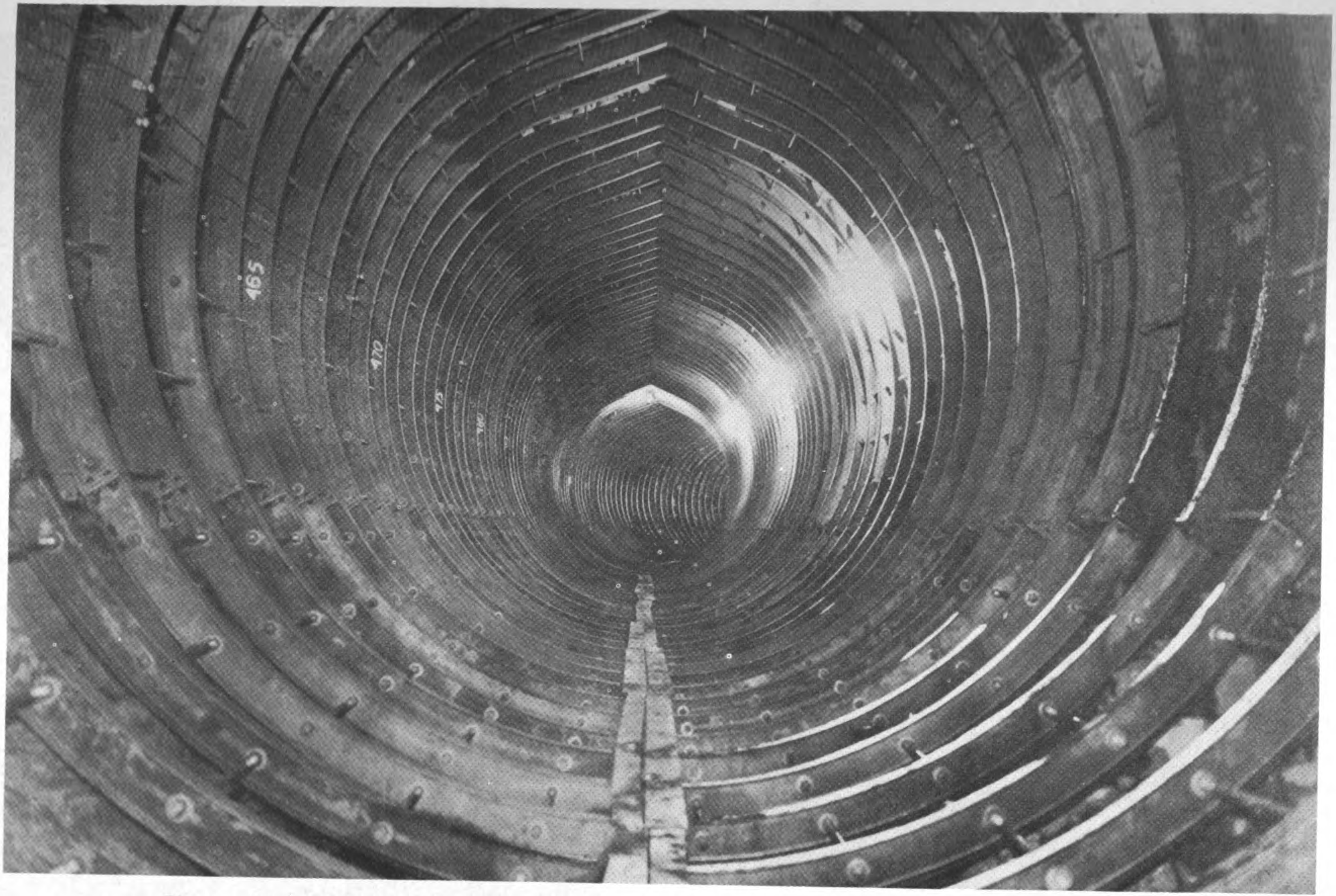

Figure 22. - Youghiogheny tunnel; showing complete steel, roof-support assembly.
Note wooden plank walkway.

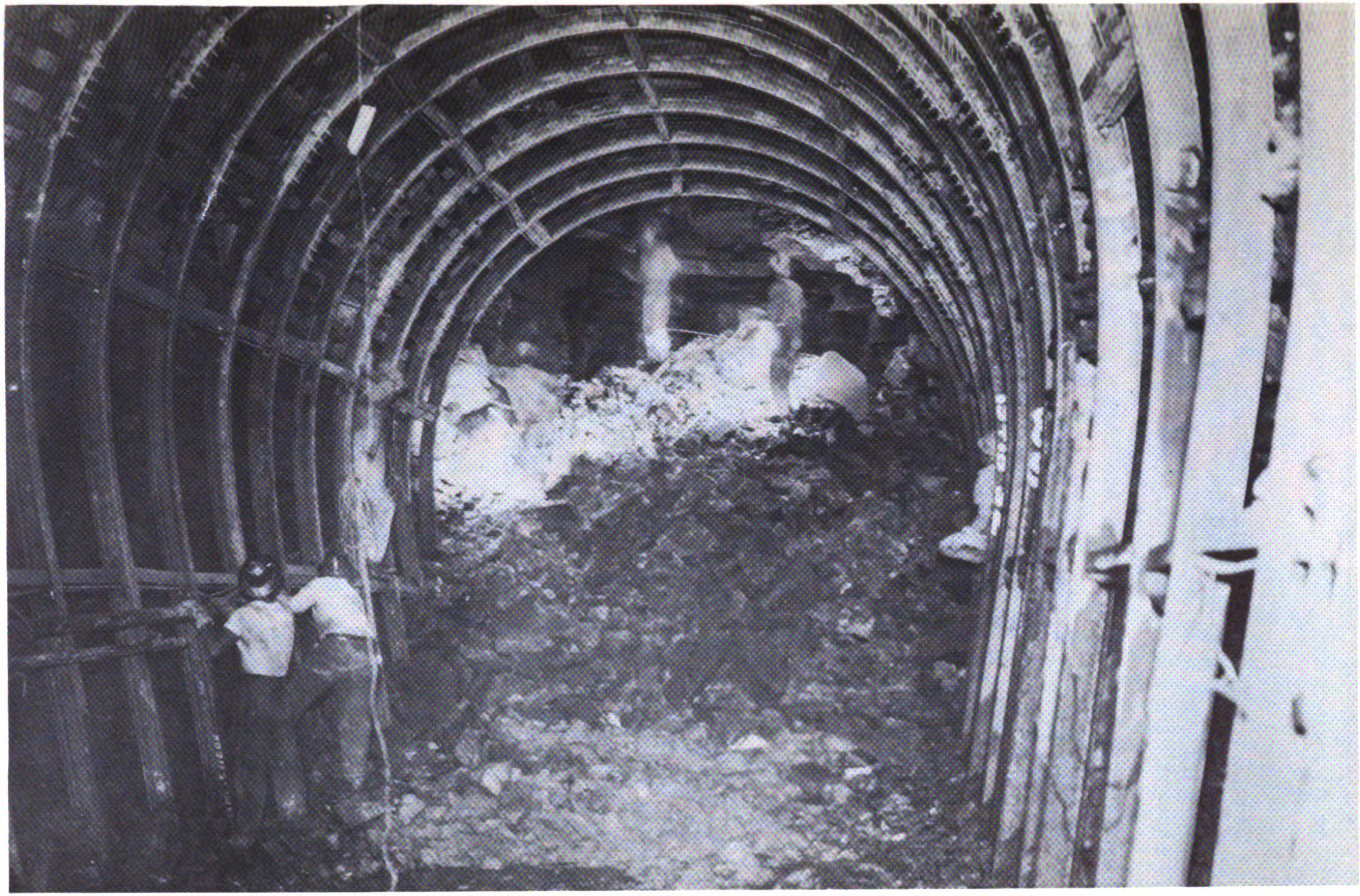

Figure 23. - Crooked Creek tunnel, looking toward heading.

About 80 drill holes ranging in depth from 9 to 12 feet, depending on the condition of the rock, were drilled for each round. A 40-percent gelatinous-type explosive initiated by electric delay detonators (0 to 10) was used for blasting.

Mucking was done with a scraper loader (fig. 20); muck was loaded into small side-dump mine cars, which were hauled by a battery-powered locomotive operating on the 36-inch gage track. A stub switch, used in making car changes, was installed in a gouged area in the tunnel and moved forward when necessary to speed up the operation. Ventilation was provided by means of a blower fan situated outside the portal and 24-inch rigid steel tubing.

The steel roof supports (figs. 21 and 22) consisted of steel H-beams with 8-inch flanges, weighing 27 pounds per foot; they were erected to form rings, each composed of six sections and bolted together. The rings were 1 foot 6 inches apart near the portals and 3 feet apart elsewhere in the tunnel. Timber lagging was placed over the steel as required by the condition of the rock. Fifteen 1-1/2-inch round-steel spacer rods were placed between adjacent rings of steel roof supports to provide rigidity for the entire assembly.

Three 8-hour shifts were worked daily.

CROOKED CREEK TUNNEL

The Crooked Creek tunnel is part of the outlet works, Crooked Creek Reservoirs Dam, Pittsburgh Flood Control, near Ford City, Armstrong County, Pa. The work was done by S. J. Grove under the direction and supervision of the U. S. Corps of Engineers, Pittsburgh District. The project was not visited during construction by the author.

The tunnel, circular in cross section, was excavated approximately 20 feet in diameter, and the finished diameter, after placing concrete, was 15 feet 6 inches. The length of the tunnel was approximately 1,320 feet.

The excavated rock was mostly hard clay; however, some coal, sandstone, shaly sandstone, and limestone were encountered.

The tunnel was driven by the heading-and-bench method (fig. 23); part of the tunnel above the springing line was kept about 10 feet in advance of the remainder. Five pneumatic water-lined drills mounted on horizontal and vertical pipe columns were used; three of these were used in the heading. Sometimes jackhammers were used to drill the bench. Approximately 65 drill holes, generally 10 feet deep, were drilled for each round.

Compressed air was furnished by four 750 c.f.m. compressors situated outside the portal. A 3-inch steel pipe line transmitted the compressed air to points of use in the tunnel.

A 40-percent gelatinous explosive in cartridges 1-1/8 and 1-1/2 inches in diameter was used. Electric delay detonators (0 to 6) were used to fire the explosive. The detonators were energized by a 440-volt, alternating-current, shot-firing circuit. Ventilation was provided by a blower fan situated outside the portal, from which air was conducted to the tunnel face through 18-inch collapsible tubing. However, it is reported that, although the fan was blowing constantly and the tubing was kept within 30 feet of the tunnel face, the ventilation was not quite adequate, because smoke did not clear promptly after blasting.

Blasted material was shoveled by hand from the top of the bench onto the tunnel floor. A mucking machine loaded both heading and bench muck into four 2-1/2-ton gasoline-powered trucks, which hauled the muck to the spoil bank outside the tunnel.

The type of roof support consisted of a three-piece set (horseshoe) - an arch set on two steel plumb posts. Six-inch I-beams weighing 14.75 pounds per foot were used. The separate sections of the roof support were spliced by bolting 4-1/4- x 3- x 1/4-inch steel flanges 24 inches long to them. Each ring (bent) of steel was provided with six spacers of 2-1/2-inch channels or 1-1/2-inch round steel rods. The roof supports were spaced 2 feet 8 inches center to center of the individual rings. An 8- x 12- x 3/8-inch steel plate was welded to the bottom of each plumb post to act as a bearing plate. The plates were drilled, and a 2-inch steel pin 18 inches long was driven through the hole in the plate and into a drill hole in the bottom rock. The purpose of the pin was to prevent the plumb posts from "kicking out." Figure 24 shows the usual roof support; note the air, water, and power lines. Figure 25 shows a roof support that failed, resulting in a roof fall and twisted arch braces. This photograph also shows the method of connecting the roof-support sections to each other. The 3-inch wooden lagging on the steel arches was used when conditions required it.

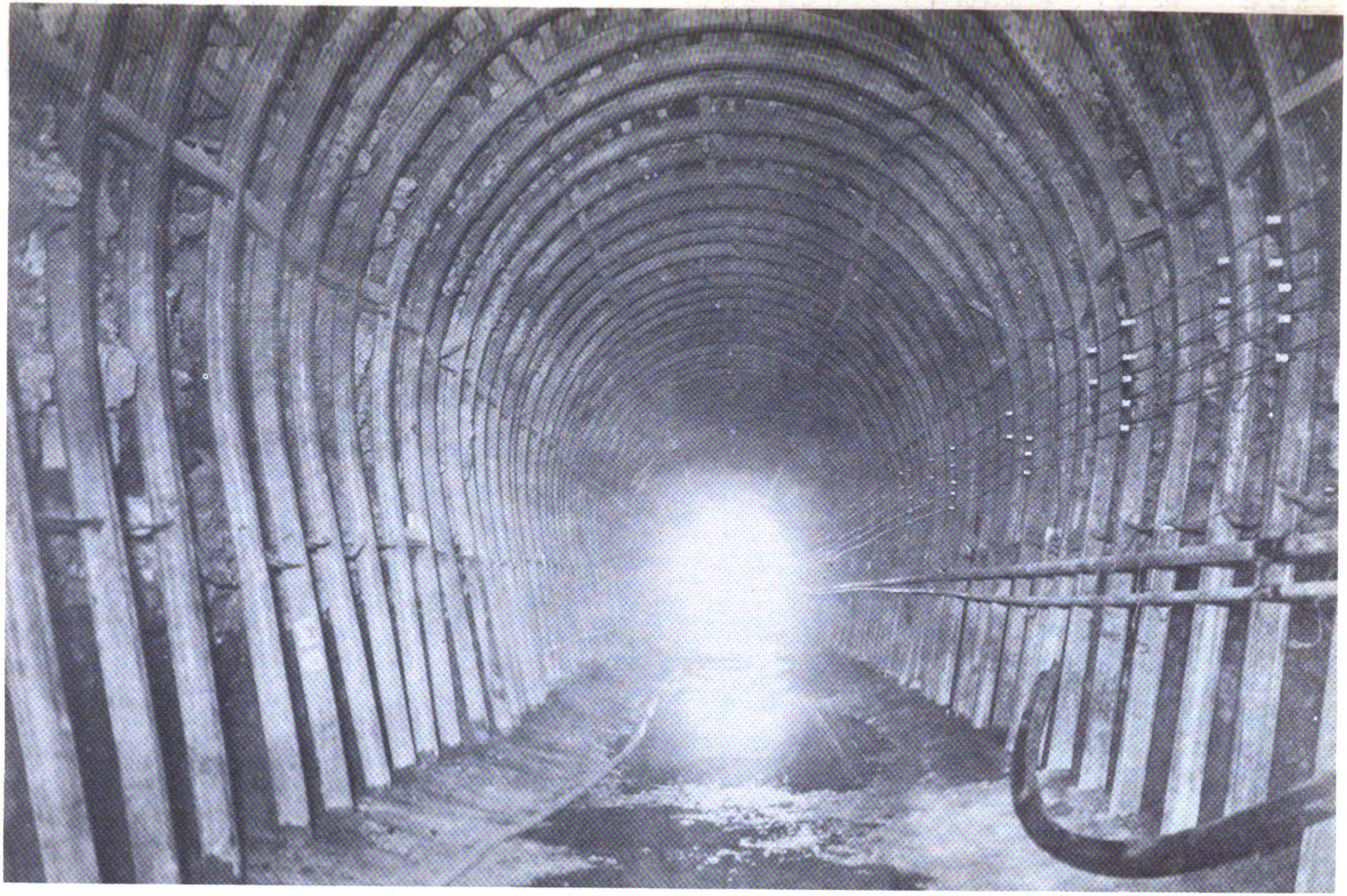

Figure 24. - Crooked Creek tunnel, looking toward outlet portal.

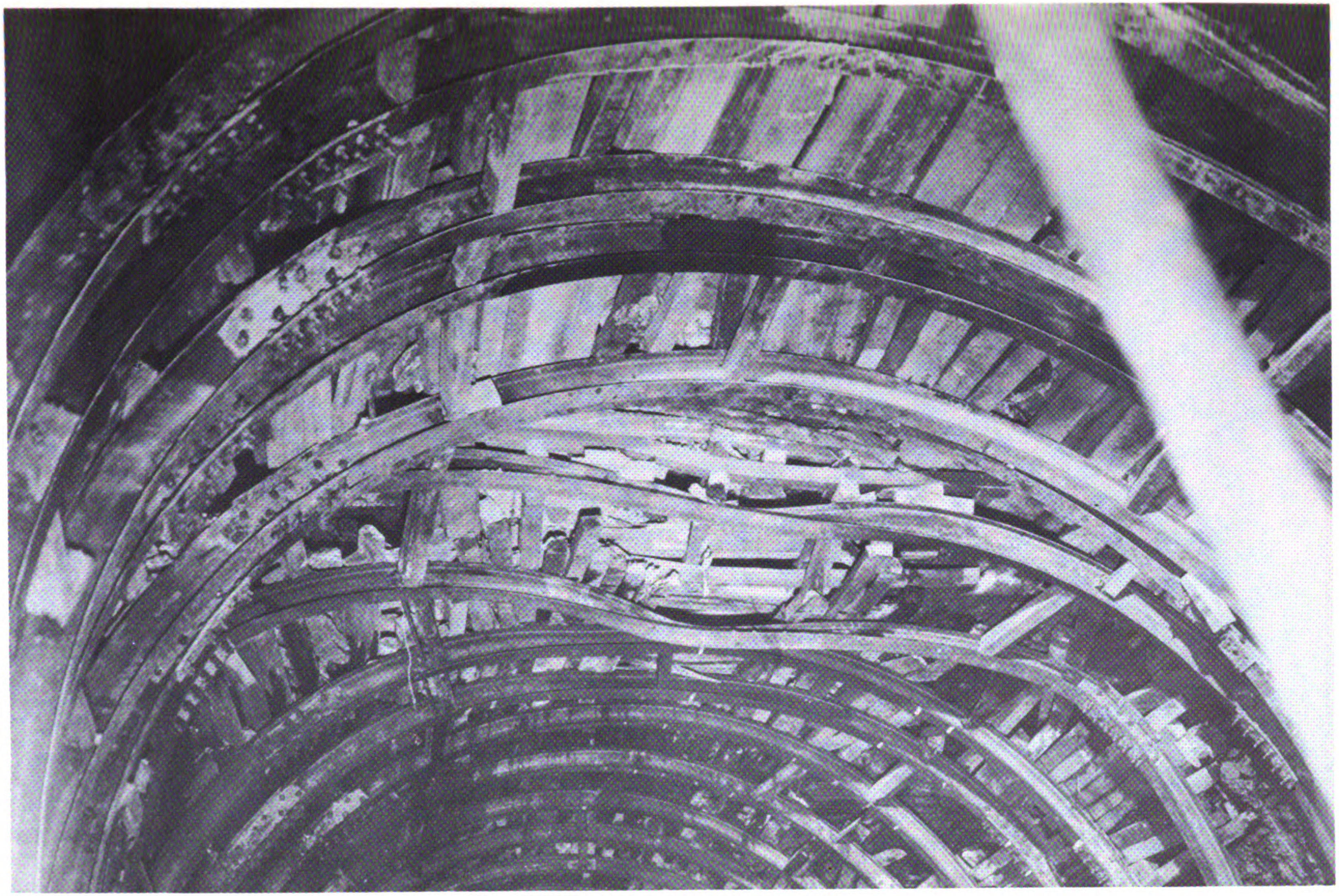

Figure 25. - Failure of roof support, showing twisted arch braces, Crooked Creek tunnel.